Citi GPS

# VIRTUAL AND AUGMENTED REALITY

## Are you sure it isn't real?

**Citi GPS: Global Perspectives & Solutions**

October 2016

**Kota Ezawa** is a Managing Director covering the Industrial, Consumer Electronics and Electric Components sector. He joined the firm in May 2006. He began his career at the Daiwa Institute of Research, covering the Utility and Machinery sectors before becoming the Small-Cap technology Analyst in 2000. Between 2003 and 2005, he covered European Technology stocks and between 2005 and 2006 he covered Japanese Industrial Electronics stocks. Mr. Ezawa graduated with a Master's degree in engineering from the Interdisciplinary Graduate School of Science and Engineering at the Tokyo Institute of Technology

+81-3-6270-4804 | kota.ezawa@citi.com

**Jason B Bazinet**
U.S. Entertainment, Cable & Satellite Analyst
+1-212-816-6395 | jason.bazinet@citi.com

**Christopher Danely**
U.S. Semiconductor Analyst
+1-415-951-1885 | christopher.danely@citi.com

**Jason Gursky**
U.S. Aerospace & Defense Analyst
+1-415-951-1672 | jason.gursky@citi.com

**Dan Fox Homan**
European General Retail & E-Commerce Analyst
+44-20-7986-4112 | dan.homan@citi.com

**Henry H Kim, CFA**
Korea Semiconductor & Hardware Analyst
+82-2-3705-0720 | henry.h.kim@citi.com

**Mark May**
U.S. Internet Analyst
+1-212-816-5564 | mark.may@citi.com

**Walter H Pritchard, CFA**
U.S. Software Analyst
+1-415-951-1770 | walter.h.pritchard@citi.com

**Michael Rollins, CFA**
N. America Telecoms & Communication Infrastructure Analyst
+1-212-816-1116 | michael.rollins@citi.com

**Thomas A Singlehurst, CFA**
Head of European Media Research Team
+44-20-7986-4051 | thomas.singlehurst@citi.com

**Kenneth Wong, CFA**
U.S. Vertical Application Software, Emerging Hardware Analyst
+1-415-951-1776 | kenneth.wong@citi.com

**Rimi Yoshida**
Japan Game Analyst
+81-3-7260-4817 | rimi.yoshida@citi.com

**Dennis Chan**
Asian Handset Sector Analyst
+886-2-8726-9086 | dennis.chan@citi.com

**Surendra Goyal, CFA**
India Strategy & Indian IT Services Analyst
+91-22-6175-9870 | surendra.goyal@citi.com

**Amit B Harchandani**
Head of European Technology Research Team
+44-20-7986-4246 | amit.harchandani@citi.com

**Rishi V Iyer**
India IT Services & Real Estate Associate
+91-22-6175-9871 | rishi.iyer@citi.com

**Atif Malik**
U.S. Semi Capital Equipment & Specialty Semi Analyst
+1-415-951-1892 | atif.malik@citi.com

**Itay Michaeli**
U.S. Auto & Auto Parts Analyst
+1-212-816-4557 | itay.michaeli@citi.com

**Jonathan Raviv**
U.S. Defense Services Analyst
+1-212-816-7929 | jonathan.raviv@citi.com

**Ashwin Shirvaikar, CFA**
U.S. Payments, Processors & IT Services Analyst
+1-212-816-0822 | ashwin.shirvaikar@citi.com

**Jim Suva, CPA**
U.S. IT Hardware & Tech Supply Chain Analyst
+1-415-951-1703 | jim.suva@citi.com

**William Yang**
Greater China Technology Hardware Analyst
+886-2-8726-9085 | william.yang@citi.com

## Expert Commentator

**Neil Graham**
Executive Producer, Sky VR Studios

# VIRTUAL & AUGMENTED REALITY

## Are you sure it isn't real?

**Kathleen Boyle, CFA**
Managing Editor, Citi GPS

The best nights watching television as a kid were when we could stay up late to watch Star Trek. This was a big treat because the show had all the right 'kid action' stuff — aliens; space travel; cool pieces of futuristic equipment like communicators, tricorders and transporters; constant requests to Scotty from the crew to either 'beam them up' or 'give them more power.' What was lost on me as a kid and I'm sure on most viewers, was how much science was being thrown at you — space exploration, physics, biology, chemistry — and how much of the futuristic equipment from the show would actually become reality — in today's mobile phones, CAT scans and MRIs. Star Trek: The Next Generation, followed the same formula as its predecessor but with updated aliens, a new 'Scotty' and a new take on futuristic equipment — the Holodeck.

The Holodeck was a room in which objects were projected as holograph images inside the room and characters could immerse themselves in anything from fighting aliens in a battle simulator to having a picnic with colleagues on the banks of an English river. It all sounded like science fiction until you find out that the Holodeck concept wasn't the idea of some creative writer dreaming of virtual reality, but instead the idea actually came to the show based on work done by Gene Dolgoff who, back in 1964, had set up a holography lab in New York.

After years of being conceptual, virtual reality is at the forefront of attention in 2016 as three VR game systems are being released and augmented reality headsets are coming closer to the market. VR/AR is now firmly on the radar as an investment theme and is expanding as an industry and we believe it will be used in a wide range of applications and in a number of different industries going forward.

Over the next five years, we believe hardware, primarily VR headsets for gaming, will be the driver of industry growth, and we think the overall VR/AR market could reach $692 billion by 2025 and continue to ramp after that. Although initially the primary content for VR will be game software, the market will then expand to include concerts, zoos, and theme parks before broadening further to encompass sports, movies, TV programs, and music.

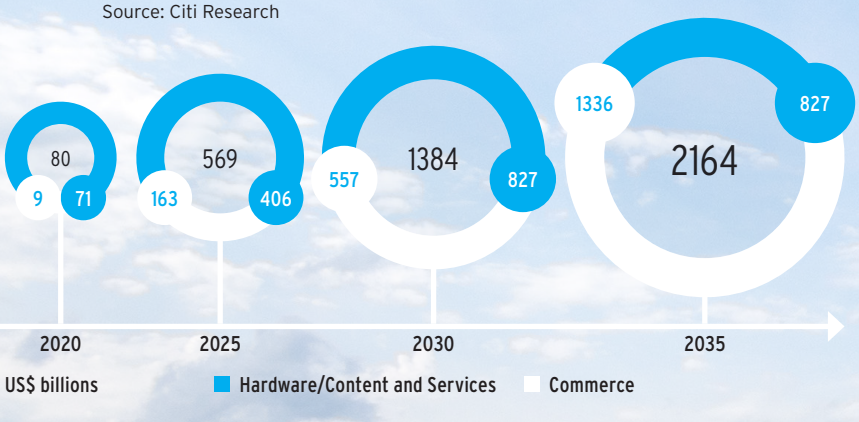
In the future, given that AR headsets allow for mobility versus VR headsets, we believe the pattern of use of AR will resemble that of smartphones, and we think AR will start to erode the smartphone market on both the hardware and the software sides. In our current model, we assume the majority of growth in the AR headset market will occur from 2025 onward and will be achieved at the expense of the smartphone market. Consumer behavior with AR devices is likely to be similar to that of smartphones, so we anticipate that consumers will increasingly use their AR headsets for commerce. Given the global e-commerce and m-commerce market is currently around $1 trillion, and is expected to rise to $4 trillion by 2030, even if VR/AR only gets a small percentage of the market, it would be a significant driver to the growth of the VR/AR market overall. Forecasting out to 2035, we believe AR could grab about 25% of the m-commerce market which would equate to almost $1.3 trillion.

Now...if I could just get that transporter to work and get me to Hawaii….

# VIRTUAL AND AUGMENTED REALITY TO BECOME AN INCREASING PART OF YOUR WORLD

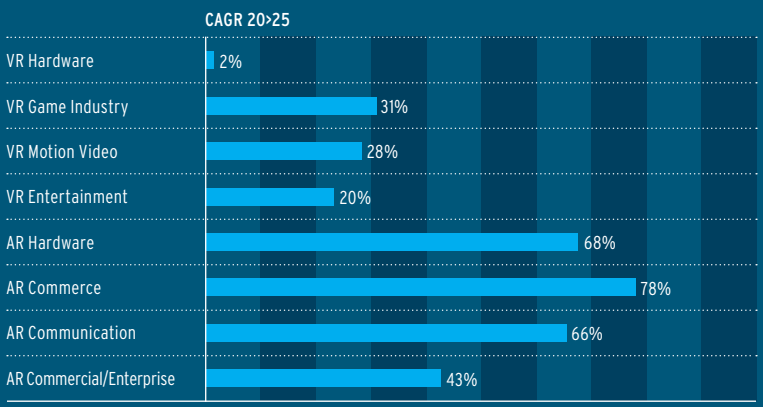
**VR/AR market could grow to $2.16 trillion by 2035 as different industries and applications adopt and make us of the technology.**

Source: Citi Research



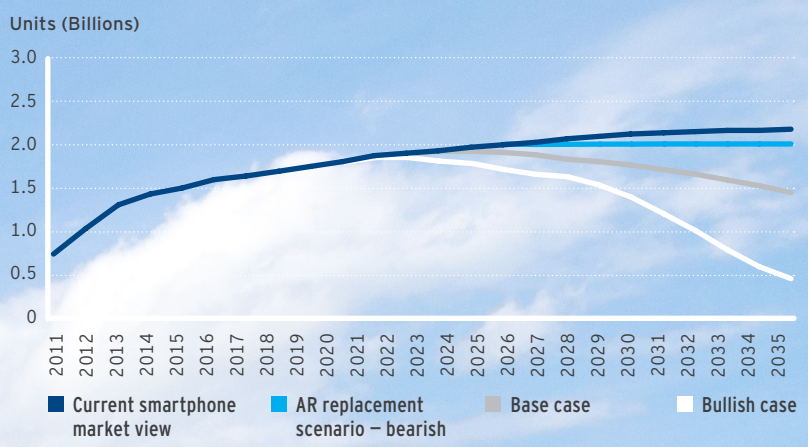

**AR hardware and VR/AR applications show strong growth from 2020 to 2025**

Source: Citi Research



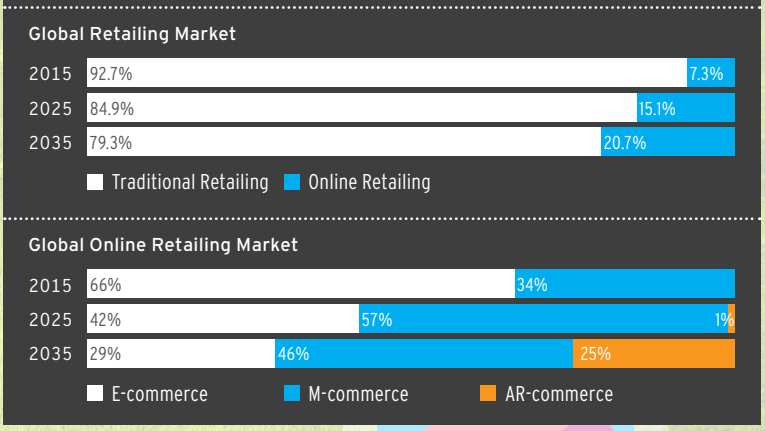
**From 2025 onward, we expect the majority of growth in the AR headset market will be achieved at the expense of the smartphone market**

Source: Citi Research




**AR commerce is expected to represent 25% of online retailing by 2035**

Source: Citi Research



# Contents

# VR/AR Related Market Will Grow as the Next Disruptive Innovation

VR/AR related market will grow

In July 2015 we introduced the potential of virtual reality (VR)/ augmented reality (AR) as a disruptive innovation in the next 5-10 years in the Citi GPS report Disruptive Innovations III. We followed that up in December 2015 with the publication of Virtual and Augmented Reality: Are you sure it isn't real?, which summarized market trends from a systematic perspective. At the time, VR/AR was becoming a hot topic in North America and Europe and the activities of start-up companies were gaining attention. In 2016, Oculus and HTC have released VR systems, and Sony has unveiled a demo system and has actively promoted VR. VR/AR is now firmly on the radar as an investment theme and is expanding as an industry. It is already clear that the VR/AR market will not be limited to gaming devices for enthusiastic fans. In 5-10 years, we believe VR/AR will probably be a part of daily life in areas like shopping, travel, and leisure and entertainment (film, music, sports, amusement parks, zoos, activities).

We estimate the total market, including infrastructure like VR/AR headsets, content and services for the devices, and e-commerce that leverages AR, at $80 billion by 2020 and $569 billion by 2025. Even excluding the retail shopping market (e-commerce), where there is little dependence on VR/AR technology, we put the market at about $71 billion by 2020, with the peak in 2032 of $855 billion.

Focus on headset market expansion over the next five years

Over the next five years, we forecast hardware — mainly headsets — will be the key driver of industry growth. We expect VR headsets to take the lead in growth, as companies aim to increase game enjoyment. For there to be explosive growth in VR headsets for consumer applications other than games, we think prices will have to come down to the $300-$400 range (average price excluding smartphone VR) over the next two to three years. AR headset technology is more expensive, so we think it will take five to ten years for these to become mainstream in consumer applications. Potential demand volume in commercial applications for VR and AR headsets looks to be lower than that for consumer applications, but we expect a steady uptake over the short to medium term.

## Trends in Major VR/AR Headsets

VR headsets have appeared in the past three years

The Oculus Rift VR system and the Google Glass AR system both appeared in limited release in 2012. VR systems started to become generally available at retailers around the end of 2015 and into early 2016, which we believe marks a turning point for the industry.

Different consumer products have different characteristics and strategies will vary. Sony's PlayStation (PS) VR, the Oculus Rift, and the HTC Vive mainly have gaming applications, while the Samsung Gear VR is used through a smartphone and will be positioned as a kind of "VR lite," mostly upgrading access to content not available on an "unaugmented" smartphone.

Even among the three devices mainly aimed at the game market, strategies will differ. PS VR assumes use in tandem with the PS4 gaming system. Content will have to be developed within a closed environment, but that content is guaranteed to work on the associated hardware. Oculus Rift development is an open market and a range of content is already functioning on model systems provided to developers. However, because processing capacity depends on the computer on which the Oculus Rift runs, there has been some concern about possible frame dropping and other problems. HTC Vive is designed to allow use of Steam VR, Valve's VR game platform.

AR is being tested ahead of diffusion

On the other hand, AR equipment is still at the trial and error stage of development. Although Google Glass was released to the general public in 2013, Google halted sales in early 2015. Epson's MOVERIO AR terminal and a number of other eyeglass-type terminals have appeared, but none of these products appear ready for widespread consumer or business use at present.

Until now, AR has been based on the idea of taking in information from the real world and displaying an interpreted version of it. Microsoft's HoloLens, announced in January 2015, relies on a more advanced concept of projecting virtual objects onto real objects, integrating the two. Playing Minecraft on the HoloLens platform, users accumulate structures on an actual desktop. Players see the virtual and real elements merged. Magic Leap, backed by Google, is under development using a similar concept. This integration of the virtual and the real has become a core AR concept.

VR headset market to become 39mn units by 2025

The earliest VR headsets appeared on the market around 2013 in a venture-like trial, but we expect the genuine ramp up of the market to start in 2016. This is when products by Oculus, which was acquired by Facebook, and Sony are to be launched.

Given the cost of the display, sensors, and other materials and the scale of volume production (small initially), we put the average unit price at $289 in 2016. Other than the Samsung Gear VR, which uses the display, sensors, and other key devices from smartphones and is priced at $99, we expect other products to be in the $400–$800 range.

We put the market size at 10 million units in 2017, 30 million around 2020 and 40 million around 2025. We think long-term equilibrium will be 40 million annually, and that the unit price will ultimately fall to less than $200.

AR headset to become 1bn unit market

We expect the market for AR headsets to be comparable to that for smartphones. Ultimately, some consumers will do away with smartphones and use AR headsets for calls and data transmission. We currently envisage AR headsets replacing smartphones in 2025–2030. Through 2025, however, we position AR headsets as a consumer device that will generate net growth in the same way as VR headsets. In the long term, we expect the extent of smartphone market substitution by AR to rise from nearly 0% in 2025 to 48% in 2035.

AR headsets require specialized displays so we expect unit prices to be relatively high. However, as with smartphones, they will serve multiple purposes, so we think volume production will bring prices down in the long term. Unlike VR, the effectiveness of AR will decline markedly once hardware quality falls below a certain standard, so we see less potential for growth in low-end products than for VR. In around 20 years' time, we would expect low-end users to continue to use low-end smartphones and mid-range and top-end users to shift to AR headsets.

We forecast the AR headset market at $17.8 billion in 2020 and $120.2 billion in 2025. Over this period, we expect the smartphone market to grow from 2.2 billion units to 2.4 billion.

AR will likely take off at the expense of smartphones

In our current market model, in working out the size of the hardware market for AR headsets we assume that the majority of growth in the AR headset market from 2025 onward will be achieved at the expense of the smartphone market. The 2025 timing is based on anticipated progress in AR headset technology; however, the shift could happen earlier if improvement in the quality of transparent displays or the development of miniature computers gathers pace.

VR/AR can still be a new growth driver for the consumer electronic equipment market

Even though we think AR headsets will erode some of the smartphone market, we still think VR and AR are the keys to the resumption of growth in the consumer electronic equipment market. In our simulation we expect VR/AR headsets to play a driving role in the digital appliance industry between 2020 and 2025.

## Biggest Markets are VR/AR Content and Services

Content and service markets larger than hardware markets

We think that headsets and other hardware will account for most of the VR/AR market value over the next five years or so, but that economic activity utilizing this hardware will expand steadily and subsequently form the core of the market. By 2020, we would expect the software and services market to have overtaken the hardware market. The hardware market will face a trade-off between the ongoing decline in unit prices for hardware and market uptake, so growth in the value of the market is likely to slow. However, as the infrastructure base of installed hardware expands, the content and services market is likely to grow rapidly over the medium- to long-term.

Market even larger when commerce using VR/AR is added in

As well as content and services, we expect the e-commerce industry to be greatly impacted by VR/AR. This outlook should provide powerful support to the cost of introducing VR/AR, and we see it as highly important. Currently, the world e-commerce and mobile commerce market is around $1billion, but we forecast growth to $4 billion in 2030. Even if it starts with only a small percentage of the market, if VR/AR is applied to e-commerce, its growth should be a powerful driver of the expansion in the VR/AR market overall. Compared with the markets for hardware and for content and services, the e-commerce market is huge in terms of value and directly connected to consumers' lives.

## Content and Services Introduced in This Report

- **Console & Mobile game** (PlayStation VR, Pokemon Go, Arcade Game)
- **Amusement & Theme park** (VR Coaster)
- **Media** (Sky, VR Movie)
- **Sports, Music** (NBA, DeNA/SoftBank, Formula One, LiveNation)
- **Marketing** (Travel agency, Real estate)
- **Automotive** (AR as evolution of HMI)
- **Education** (zSpace AR program)
- **Medical & Healthcare** (Diagnostic, Simulation, Training)
- **Industrial use, Factory operation** (Work and operational support, NEC and Fujitsu)
- **Aerospace & Defense** (Commercial aerospace, simulator, Military)
- **Office use** (Conference, trading systems)
- **VR/AR Commerce** (Advertisement, Internet shopping, Payment)

## VR/AR Outlook

Changing our world

By projecting virtual objects or people into real space through the use of AR, it has become possible to intuitively convey images of objects or people that previously had to be imagined. By superimposing 3D computer-generated imagery over real-time images, AR allows users to view and touch objects from different angles in an almost realistic fashion and to use a gyroscope to adjust views and aspects. This not only offers greater convenience, it may also affect human sensibility. Put another way, humanity's desire to own material things and infrastructure could wane and the importance of objects existing physically before one's eyes could also diminish.

In the world of AR, it is also possible to superimpose text, statistics, or other information forms over real-life images or background scenes. We believe this will bring life changes similar to those triggered by the birth of the Internet. As this technology not only allows the explanation of immediate events/phenomena even where there is no prior memory or knowledge, it also makes it possible to obtain information which augments existing knowledge, such as up-to-date information and statistics (support ratings, sales, traffic news, etc.). Customizing such information to an individual's needs also appears feasible, especially when linked to profiles, data sets, and productivity applications relevant to that user.

The use of VR can simulate environments that give the impression almost of a novel scene. Using a headset or similar device, the VR visitor normally stands in a certain space, or in some cases sits in a chair or lies on a bed. VR not only includes sight and sound, but if sensors corresponding to each of the five senses are applied to the body, the overall virtual experience can deliver a level of awareness that transcends the physical body. For the user, VR heightens the perception of being physically present in a non-physical world, a perception that is created as the user's awareness of physical self is transformed by being immersed in a virtual space. We believe the use of VR in entertainment applications such as games and movies will deliver a relatively more realistic experience. However, we think VR could ultimately result in human consciousness itself being recreated within the virtual environment.

IOT could absorb VR amid advances in networks and computing

We think VR could play a major role in humanity's future. Specifically, we think rapid advances in hyper-capacity networks and ultra-miniature/high-performance computing could see the nascent IoT eventually absorb VR as a key tool for accessing all data on things and events uploaded to and stored on networks. Our near-term roadmap has VR succeeding telephones, TVs, and the Internet as the next major advance in human communications.

As this occurs, we expect VR to be combined with AR to create a virtual space as precise and detailed as a photograph. We expect further technological advances to eventually enable the five human senses to be re-created in the virtual environment as well as—ultimately—human consciousness itself. This outlook for the future is currently transitioning from mere futurist vision to the actual roadmap used by scientists involved in computers, IoT, and VR. We think future technological advances will make VR/AR a platform that transforms human lifestyles.

# What Is VR and AR?

## Virtual and Augmented Reality is Coming

VR/AR allows you to experience the unreal

Virtual reality (VR) and augmented reality (AR) refer to the experience of a high-resolution graphic or photographic environment through a cutting-edge device (such as a headset or eyeglass-type terminal) that draws on advanced displays, graphics semiconductors, motion sensors, and headphone technologies. VR and AR allow users to take in new information via recognition of artificially-created objects or by seeing things that are usually difficult to discern.

Virtual reality (VR) users experience the illusion of inhabiting an artificial space

Virtual reality involves a goggle-type display that completely covers the field of view. Wearing the display, users experience the illusion of inhabiting an artificial space. Users see computer graphics or photographs that move in tandem with movements of their head, neck, and body, and hear sounds in the virtual world through headphones. If the quality of the graphics is high enough, users might come to accept the idea that they are actually within an artificially-created world or are in a place that would otherwise be difficult to access.

Augmented reality (AR) allows for mobility, but users experience the real world with superimposed images. Augmented reality, while similar, does not necessarily immerse the user in a virtual space. Instead, users experience AR through computer-generated images superimposed over their view of the real world. AR is characterized by the use of computer graphics while recognizing the real world at the same time. AR allows computer graphics to appear like real images within real spaces. Perhaps the most important feature of AR is that it allows user mobility.

**Figure 1. Example of VR Headset Device (HTC Vive)**


Source: HTC

**Figure 2. Example of AR Headset Device (Microsoft HoloLens)**

Source: Microsoft

## VR: High Performance Displays and Sensors

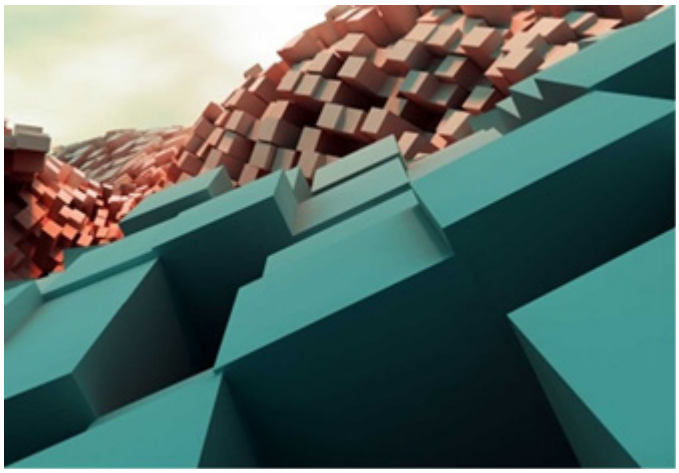
VR goggles aid the creation of artificial space by completely covering the user's field of vision

How is the virtual reality illusion created? VR utilizes two displays so that it appears computer graphics or photographs (still and moving images) are being viewed with both left and right eyes (in some cases an image is displayed on a screen that is divided into two sections). Users don goggle-type displays that completely cover their fields of vision, so they feel, illusorily, as if they have placed themselves in an artificial space. As users turn their heads to the right, the images move smoothly in tandem rightward into the field of vision. If users look upward, the skies might open up, studded with stars. If users don headphones they can hear the sounds of a virtual world (sometimes birds chirping or sometimes machine guns and combat aircraft), often causing users to lose confidence in the knowledge of their exact location.

Figure 3. VR: PlayStation VR – Wearing Goggles

Source: Sony Interactive Entertainment, Inc.

Figure 4. VR: Getting Lost in an Imaginary World



Source: 123RF

## AR: Transparent Lenses Do Not Block Vision

WAR users remain immersed in their real world spaces

Augmented reality (AR) resembles VR but it is not necessary for users to immerse themselves in virtual spaces. Indeed, it can be used by overlaying the requisite information on the scenery (field of vision) in the current world, with computer graphics being used while users are still aware of the current world. In AR, it is possible for users to view objects, people and information such as words and arrows created by computer graphics as real-life images that appear to have risen up in real space. Unlike in VR, users view AR images and information such as computer graphics while remaining aware of the real-world space, so they are expected to use AR while performing everyday activities like walking in real spaces, riding in vehicles, and engaging in communication.

Figure 5. AR: Computer Graphics Overlaid Onto Real World Scenes

Source: By Edward (via Wikimedia Commons).

Figure 6. AR: 3D Holograms You Can Reach Out and Touch

Source: 123RF

### VR/AR Outlook

VR has potential for use in theme parks, real estate, travel, and entertainment. AR has the potential for widespread usage in mobile commerce

The leading market for VR is games and images that look to pursue the most intimate experiential development using the sense of immersion. Both the gaming and imaging industries have taken the lead in the generation of visuals that create this immersive sense via the technological evolution of VR. We think VR using 3D goggles could give rise to significant innovation in the way content is created, watched, and played. Games and movies can only be experienced in one place, which matches well with VR. We also think there is considerable potential for the use of VR in amusement parks and theme parks. For real estate or travel agents, we think VR/AR holds promise for marketing materials designed to accelerate business, for instance by leveraging VR to display remote locations or mock-ups of properties that do not yet exist.

However, we think that AR has even greater commercial potential and envisage the market growing larger than that for VR. Moreover, AR is delineated on the skein of a real space, so placement precision and the quality of the sensor response, for instance, need to be at an even higher level than in VR. As a result, we think the hardware devices, such as smart eyeglass frames, that realize AR will develop into a larger market than hardware for VR. After hardware, we are most optimistic about consumer markets and think AR has the potential to be a major constituent element of contemporary mobile commerce. Moreover, we would expect the information itself that is overlaid and displayed as AR on real spaces to form a major constituent element of the market value. That is, we envisage a structure whereby the user puts on an eyeglass-style device and makes purchases because he or she obtains information in front of their eyes about the degree of popularity of a product and how well it has sold to date. We also think advertisements might be displayed. It is not easy to make projections of the size of the markets for these constituent elements, but the main constituents are in our view likely to be hardware, commercial services, and entertainment services, and we note the potential for rapid market expansion.

## Categorization

### VR/AR Positioning: How It Will Get There

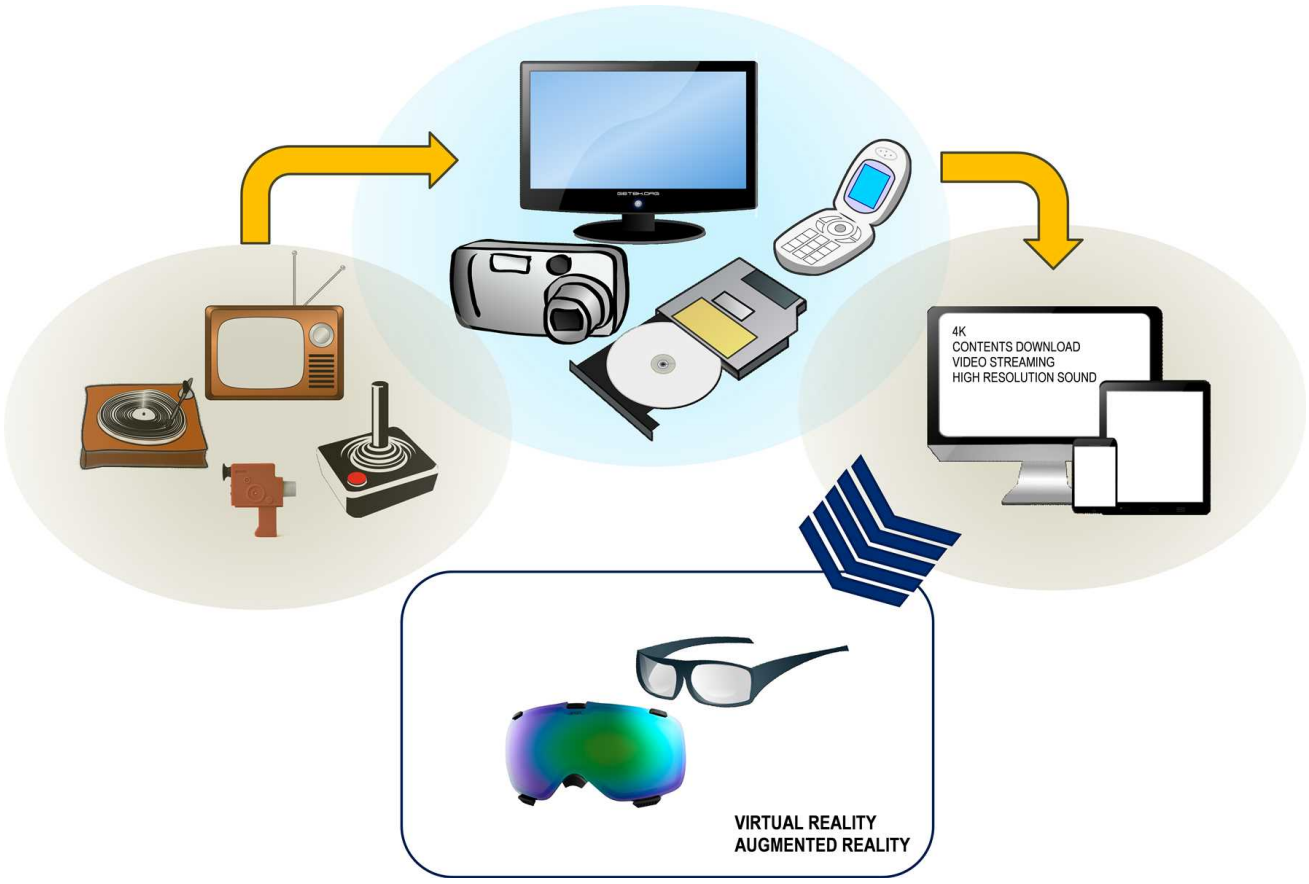
Media like sound recordings and photos have long provided virtual reality-like experiences

People have long been familiar with the concept of virtual reality-like experiences. They say things like, "It felt just like flying in the sky," or "The baby is happy, as if being held in its mother's arms." Media such as sound recordings, photography, and video recording have long provided pseudo-live experiences. Until about 30 years ago, monaural recordings, analog photos, 8mm film footage, and analog TV were the main providers of these experiences. With the aid of the user's imagination, these media provided a strong enough sense of reality to engage people. Game consoles had also already appeared around that time, creating a new market.

The evolution of sound and images has paved the way for VR/AR development

Recording and playback equipment evolved with the introduction of CDs, digital cameras, digital camcorders, and digital television. Games and movies moved into the digital realm. Higher image quality allowed for a heightened sense of realism. . The typical household device for enjoying movies, dramas, sporting events, and concerts shifted from a 21-inch CRT TV to a 52-inch LCD TV, and 4K TV appeared. Music moved in the direction of downloads and streaming, and high-resolution audio appeared at the same time. In addition, consumer-generated media began to dominate personal computer and smartphone screens.

Figure 7. VR/AR an Extension of Previous Electronics Technologies




Source: Citi Research

## History of VR

While 2016 could be considered as the birth year of VR/AR, it is important to note that it has arrived after a half-century gestation. Products that specifically incorporate the concept of VR appeared in the 1980s. However, there have been multiple examples of products that use less advanced technologies to provide entertainment by populating the field of vision with video and images.

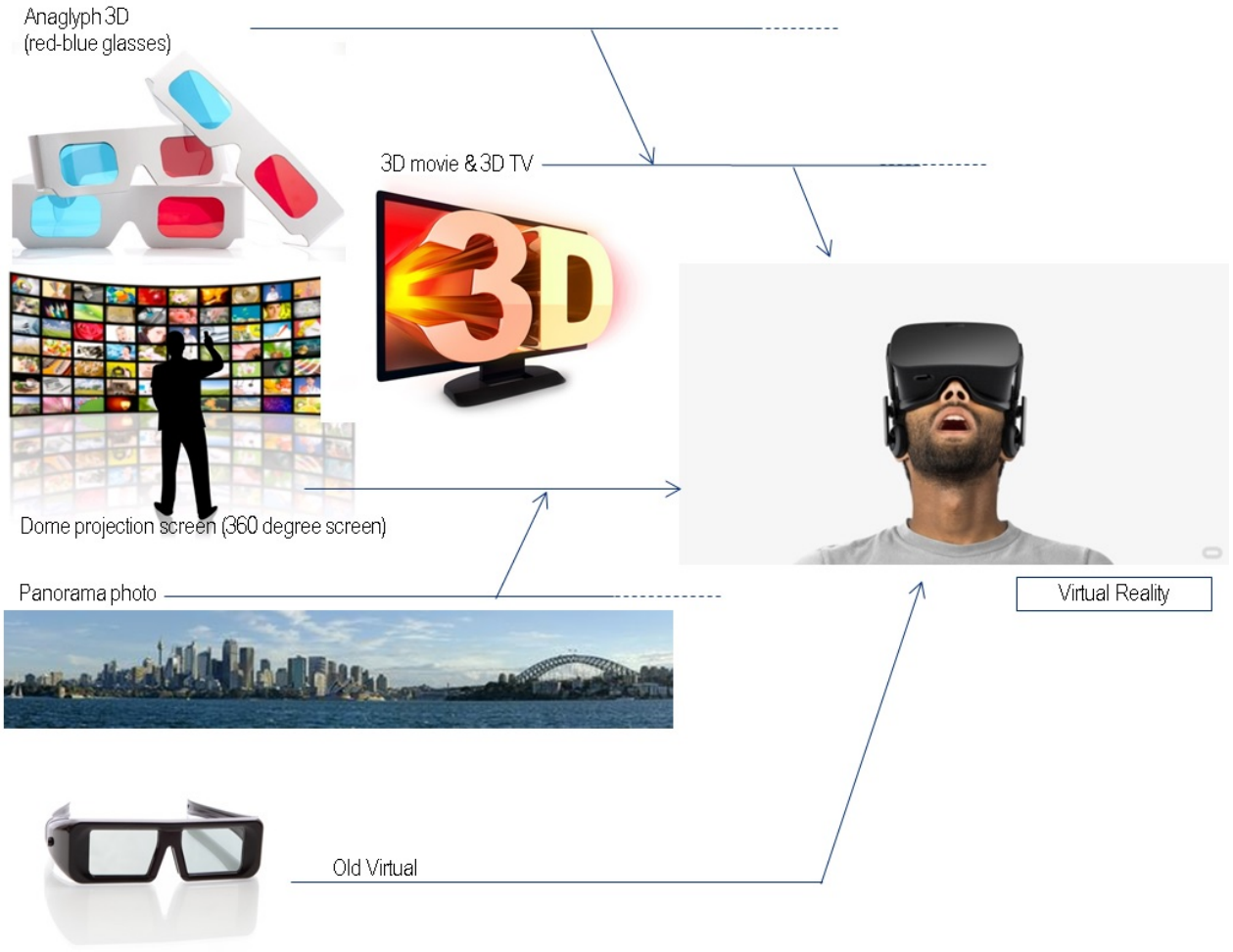
VR/AR arrived in 2016 after half a century of gestation

Panoramic photographs were probably the closest thing to the first iteration in the development of VR/AR technology and products. Panorama viewers with red and blue cellophane lenses enabled users to experience photos in 3D. Dome screen projectors, which project celestial sphere images (360 degree), appeared in the early 2000's. Although it utilized 2D technology, it allowed people inside the dome to view an image in every direction. Around 2008, cinemas and TVs began to adopt 3D video formats to attract customers with a new entertainment experience. This technology realized a 3D sensation by displaying different images in each eye and required viewers to wear special 3D glasses.

Head tracking with VR headsets create an optical illusion giving wearers an immersive experience

VR can be described as a more sophisticated version of 3D. When a user wears a VR headset, the images that they see change with the movements of their head. Head tracking creates an optical illusion that gives the wearer an immersive experience. VR headsets began to appear on the market in 2015, and the entry of large companies into the VR domain in 2016 has raised expectations that the VR market will take off.

**Figure 8. Modern — Evolution to VR**




Source: Oculus, 123RF, Citi Research

## History of AR

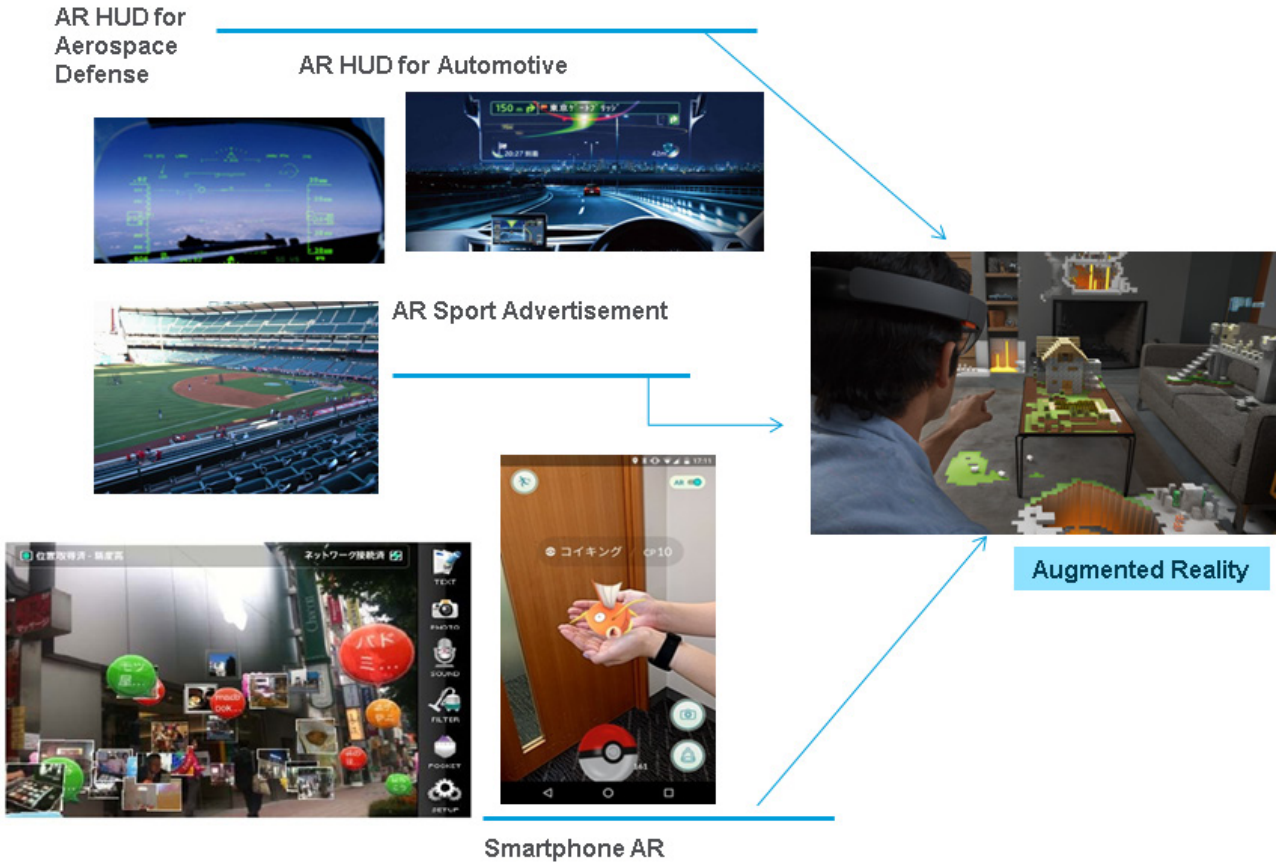
AR research dates back to the 1980s

Research into AR started in earnest in the 1980s and mainly advanced in the aerospace and military fields. A small consumer market for consumer technology appeared in 1990. Perhaps the most recognizable application of AR technology is the overlays used in TV sports broadcasts. For example, in NFL game broadcasts, computer graphics (CG) are used to highlight the line of scrimmage and the first-down line or a particular player, and together with camera work, continue to focus on a physical object or specific position. We are now seeing many cases in which AR is used to display ads for the TV viewership "at" the sporting venue in question. At televised ice hockey games, advertisers are able to insert 'virtual advertisements' for the TV audience on the glass surrounding a hockey rink.

Sekai Camera and Pokémon Go have attracted users to the potential of AR technology

Sekai Camera, an AR app released in 2008, is a relatively well-known example of the application of AR in the consumer domain. Launched in Japan in 2009, Sekai Camera was the first AR app developed for the smartphone and took four years of trials to complete because of business model issues. Sekai Camera allows people to use their smartphone to overlay AR contents on everyday scenes. The smartphone game Pokémon Go has brought the potential of AR technology to the attention of almost 100 million users.

Figure 9. World of AR




Source: Rockwell Collins, Pioneer, Sekai Camera, Niantec, Microsoft, Citi Research


GPS sensors on AR glasses allow for user mobility

AR glasses use transparent lenses resembling eyeglass lenses equipped with a power source and backlights to brightly overlay computer-generated edge information onto the transparent lenses. Because these glasses usually allow the user to see and react to the external environment (unlike VR goggles), they also include image sensors. Since mobility is a requirement, AR glasses are equipped with GPS sensors.

Technological hurdles to AR are high; however, we expect market growth in the long term

Despite these developments, there are still technology challenges. As connecting to a personal computer or a PS4 limits mobility, it therefore becomes necessary to embed central functions such as image processing within the AR glasses. Supporting high-level image processing over extended periods of time requires very high-capacity batteries and batteries of a high energy density, given that they have to be part of the worn apparatus. The ultra-high-performance electronic components and semiconductors required are not yet available with current technology. Therefore, AR is properly considered a promising technology over a longer time horizon than VR. Early versions with basic functions but certain limitations are expected to appear in 2016–2017. Full-fledged AR systems are likely to appear between 2019 and 2022 (based on model numbers and assuming consistency of development). Mobility will be a strong source of appeal. We believe a significant number of applications that people use smartphones for today may be replaced by augmented reality technologies, making a long-term growth scenario plausible.

AR systems require more specialized graphics than those on VR systems

AR systems are characterized by computer graphic displays superimposed on the user's view of the real world — which involves more specialized computer graphic projection equipment than required by VR technologies. Various approaches have been explored using transparent polymers or glass to create prism-shaped elements that insert images into a portion of the user's field of view.

Devices that mount a prism in front of the viewer's eyes can be considered the first iteration. The next generation is expected to include information tools (called "scouters" and by other names) that cover one eye or that the user views with both eyes to see projected computer graphics over a broader field of view—devices sometimes depicted in movies and comics today. Ultimately, AR glasses are expected to be eyeglass-type devices that cover the entire field of view with transparent lenses that allow projection of images of non-transparent objects or people, creating the illusion of their actual existence within real space.

AR headset sensors include GPS sensors and image sensors, among others

Sensors used in AR headsets are similar to those used in VR equipment. They include acceleration sensors, angular velocity sensors, and geomagnetic sensors. Because of the need for mobility in the case of AR, GPS sensors will be important to include. AR systems are also very likely to include image sensors in order to accurately analyze the user's surroundings. AR equipment will need to continuously capture a scene very closely replicating the user's view in real time and use the data to determine the appropriate position of computer graphic overlays, suggesting that pressure to improve the precision of AR systems will continue to grow. We believe advanced AR systems will also require proximity sensors, ambient light sensors, and inertial sensors, although these may not be core components.

## VR/AR Classification

Live-action VR presents more development challenges than computer graphic VR

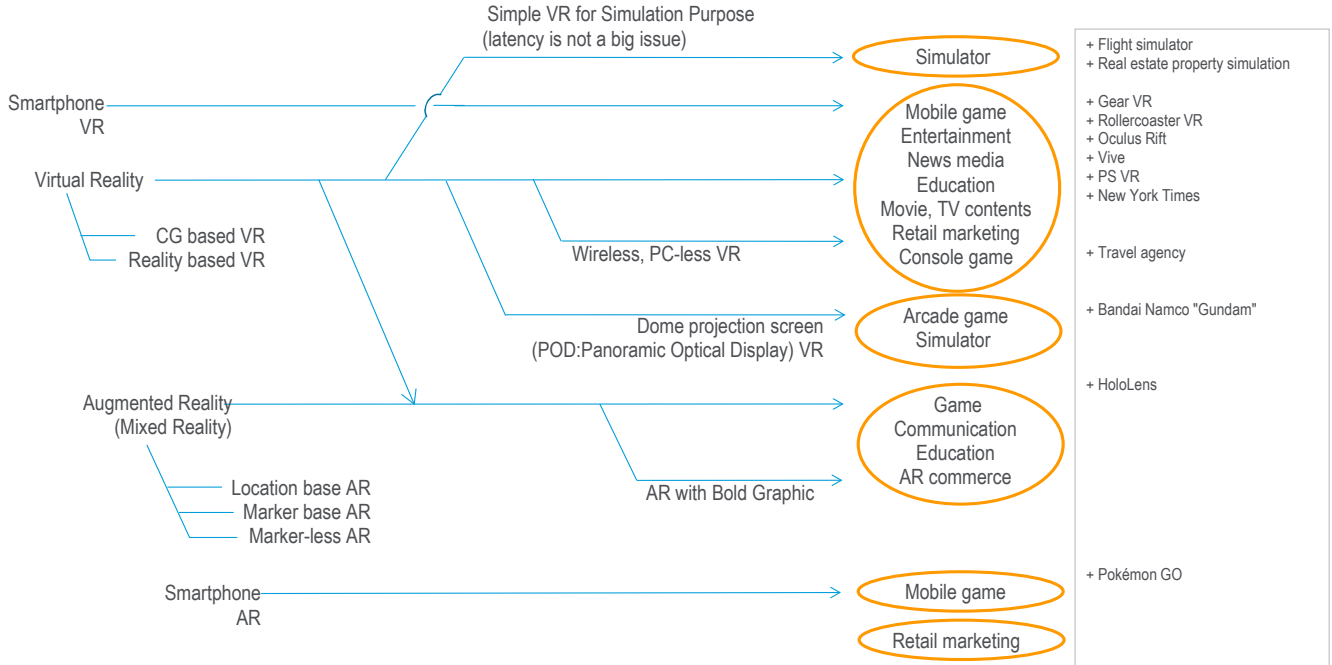
Modern VR and AR systems employ a number of core techniques. Headsets are commonly used to provide the immersive experience, but applications and content production methods can differ.

The experience a VR headset provides is divided into computer graphic (CG) and live-action types. While files are very large, using CG enables a comparatively true-to-life experience via content with a 360-degree view or with time-lapse images. There are several hurdles to realizing live-action VR. First, it requires a camera that can capture images in a 360-degree field of view or something close to it. The use of still images, taken using several cameras that have fish-eye lenses, and video to create VR is advancing rapidly. Unlike CG, however, it is difficult to create multiple points of view with live-action VR. In other words, someone can view a virtual surrounding while standing still, but often they are not able walk toward objects and take a closer look.

AR uses transparent glasses and miniature projectors to display computer graphics in the real world. The computer graphics consist of actual images taken separately (of people and the like), and in the future will likely include live images from remote locations. If the computer graphics are photographed, then it is easy to digitally isolate the information intended for display. The amount of information can then be controlled during production, so CG can be achieved to some extent with current technologies. However, many issues remain at this point, including the difficulty of making headsets mobile, and the difficulty of including all the information needed to making AR images (computer graphics) in high resolution and with a 360-degree view. Even so, 2016 has been a year of significant innovation in AR, with the release of games that use AR on a smartphone display and the development of a large range of specialized headsets and wireless systems with data processing computers. With actual images, technologies are needed to synthesize the intended image via digital processes and chroma key processing, and image transmission requires compatible protocols for the transmitter

and the receiver. In addition, the high-speed transmission of a large amount of data will require transmission bandwidth and transmitter and receiver processing capacities far in excess of current devices. This is unlikely to be realized in the near future.

**Figure 10. VR and AR Categorization**

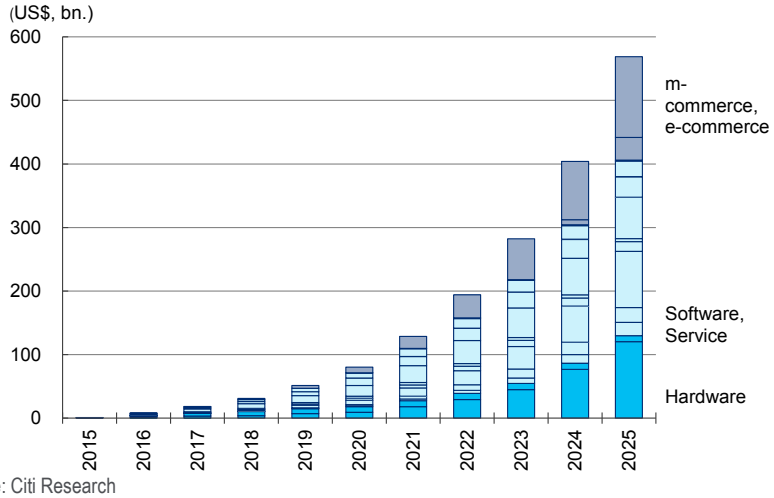



Source: Citi Research

## Market Size and Growth

Based on the aforementioned classifications, we believe the VR/AR market will expand to $7.6 billion in 2016, $18.2 billion in 2017, $80 billion in 2020, and $569 billion in 2025. We forecast the market for headsets and other hardware will expand from $3.6 billion in 2016 to $130 billion in 2025 (a compound annual growth rate, or CAGR of 49%), and the market for software, contents, and services will expand from $3.9 billion in 2016 to $276 billion in 2025 (61% CAGR). In the next chapter, we introduce technologies and systems for VR/AR hardware and software, content, and services.

**Figure 11. VR/AR Market Scale Forecasts**




Source: Citi Research

# VR/AR Hardware & Technology

## Headset Makers: Trends in Major VR/AR Headsets

VR/AR headsets started to appear in limited release in the past three years

The Oculus Rift VR system and the Google Glass AR system both appeared in limited release in 2012. VR systems started to become generally available at retailers around the end of 2015 and into early 2016, which marks a turning point for the industry.

Different consumer products have different characteristics, and strategies will vary. Sony's PlayStation (PS) VR, Oculus Rift, and HTC Vive mainly have gaming applications, while Samsung Gear VR is used through a smartphone and will be positioned as a kind of "VR-lite," mostly upgrading access to content not available on an "unaugmented" smartphone.

Even among the three devices mainly aimed at the game market, strategies will differ. PS VR assumes use in tandem with the PS4 gaming system. Content will have to be developed within a closed environment, but that content is guaranteed to work on the associated hardware. Oculus Rift development is an open market and a range of content is already functioning on model systems provided to developers. However, because processing capacity depends on the computer on which Oculus Rift runs, there has been some concern about possible frame dropping and other problems. HTC Vive is designed to allow use of Steam VR, Valve's VR game platform.

AR is being tested ahead of diffusion

On the other hand, AR equipment is still at the trial and error stage of development. Although Google Glass was released to the general public in 2013, Google halted sales in early 2015. Epson's MOVERIO AR terminal and a number of other eyeglass-type terminals have appeared, but none of these products appear ready for widespread consumer or business use at present.

Until now, AR has been based on the idea of taking in information from the real world and displaying an interpreted version of it. Microsoft's HoloLens, announced in January 2015, relies on a more advanced concept of projecting virtual objects onto real objects, thereby integrating the two. Playing Minecraft on the HoloLens platform, users accumulate structures on an actual desktop. Players see the virtual and real elements merged. Magic Leap, backed by Google, is under development using a similar concept. This integration of the virtual and the real has become a core AR concept.

Figure 12. Major VR/AR Headsets

| Company<br>Product<br>VR or AR | Sony<br>PlayStation VR<br>VR | Facebook<br>Oculus Rift<br>VR | Samsung<br>Gear VR<br>VR | Valve / HTC<br>HTC Vive<br>VR | Google<br>Google Glass<br>AR | Seiko Epson<br>Moverio<br>AR |
|---|---|---|---|---|---|---|
| 2011 | | | | | | **BT-100 Released** |
| 2012 | | Prototype announcement | | | Prototype announcement | |
| 2013 | | Released for Developers | | | Released for Developers | |
| 2014 | Announcement (Project Morpheus) | New Proto<br>New Model<br>Bought by FB<br>Released<br>Gear VR announcement | Gear VR announcement<br>Released for Developers | | **Released for consumer** | BT-200 Released |
| 2015 | New Prototype announcement<br>PlayStation VR announcement | Alliance with MSFT<br>Announce consumer model | Released for Developers<br>**Released for Consumers** | HTC Vive announcement<br>Released for Developers | **Discontinued** | BT-2000 Released (for business) |
| 2016 | **To be released** | **Released for Consumers** | | **Released for Consumers** | | |

Source: Company data, Citi Research

## PlayStation VR

Figure 13. Sony PlayStation VR

Source: Sony Interactive Entertainment, Inc.

Sony announced Project Morpheus, a prototype PlayStation VR model, in March 2014 at Game Developers Conference (GDC) 2014. In the following year, at GDC 2015, the company unveiled a new prototype. In September 2016 Sony introduced the PlayStation VR name and announced plans for its full release in October 2016. The system will use a 5.7-inch organic electro-luminescent (EL) display with a 1,920 x 1,080 resolution (960 x 1,080 in each eye), a 120Hz refresh rate, and a viewing angle of about 100 degrees. Because the system will be hard-wired (with an HDMI connection) and must connect to PS4 equipment, users will have to own a PS4 system, but we believe problems caused by inadequate graphics processing capability (such as dropped frames) are unlikely to occur.

## Oculus Rift

Figure 14. Oculus Rift

Source: Oculus

Oculus VR, Inc. announced its first prototype at the Electronic Entertainment Expo (E3) in June 2012. In March 2013, it launched the Oculus Rift DK1 as a developer model. Priced at $300, resolution was 1,280 x 800 pixels on a 7-inch liquid crystal (LCD) display. Facebook acquired Oculus VR in March 2014 for $2 billion. The company launched the Oculus Rift DK2 in the following July, priced at $350 with a resolution of 1,920 x 1,080 pixels on a 5.7-inch organic EL display. The device connects to a personal computer with an HDMI cable and is treated as an auxiliary display with a 75Hz refresh rate. Oculus recommends the controlling PC use an NVIDIA GeForce GTX970 or AMD Radeon R9 290 graphics processor or better. The company also has demanding central processing unit (CPU) and memory recommendations. In June 2015, the company announced an Oculus Rift model for general release, which was launched at the end of March 2016. Oculus VR has also announced a partnership with Microsoft. The final release version will include an Xbox One controller. Edge of Nowhere (Insomniac Games), Chronos (Gunfire Games), and other titles are currently under development and we believe other game studios are also developing titles. Available content appears set to expand.

## HTC Vive

Figure 15. HTC Vive


Source: HTC

HTC announced the HTC Vive at Mobile World Congress (MWC) in March 2015. HTC Vive was developed in collaboration with Valve, which runs the Steam game distribution service, part of the SteamVR project. Gaming will be the main application. HTC Vive was launched in early April 2016 and uses a 2,160 x 1,080 pixel organic EL display with a 90Hz refresh rate. It will require a wired connection to a personal computer. Its Lighthouse position detection system will allow the user increased mobility while wearing the equipment versus a PS VR or Oculus user. The system is also capable of recognizing multiple devices, allowing it to reflect the movements of other players within the VR environment.

**Latest Updates on HTC Vive:**

- **Leveraging Ali Cloud for Better VR Experience:** On August 9th, HTC announced the formation of a partnership with Ali Cloud on VR development. HTC expects that all VR content will be on the cloud in the future and also believes the company can leverage Alibaba Cloud's platform to provide a better VR experience. The company says if VR games were to go on-line in the future, Ali Cloud's CDN (content delivery network) can achieve better data delivery and provide a smoother user experience.

- **HTC Viveport to Generate Service and Content Distribution Revenue:** Viveport is essentially an app store in a VR context. In August 2016, HTC launched the developer version of HTC Viveport globally. HTC aims to become a VR platform provider and generate revenue through both service and content distribution from Viveport. Viveport will offer in-app purchase to serve as an incentive for developers, and we forecast HTC to obtain ~30% revenue sharing from each in-app purchase.

  HTC claims that the service and app revenue generated from Viveport will come with higher gross margins than the hardware sales of HTC Vive, albeit uncertain on the operating margin level. In addition, HTC indicates that there won't be any conflict with Valve's Steam platform, as Steam focuses on gaming while Viveport focuses on non-gaming contents.

- **Partnership with Valve:** HTC partnered with Valve, known for its award winning PC games (Half-Life and Counter Strike) and as the largest PC game platform (Steam) operator in the U.S. Both companies aim to deliver a high-end VR experience through best-in-class technology and content. Despite the possibility that Valve may authorize its Lighthouse tracking technology to be used by other VR hardware makers, HTC believes their partnership with Valve is a good one, given HTC's strength in manufacturing high-quality VR headsets. HTC also claims that the algorithm of its tracking system is a key challenge for hardware makers to address, making it a high entry barrier.

- **Competitive Edge Against Oculus Rift**: HTC believes Vive's laser-based tracking solution is better than Oculus's camera-based solution in terms of precision. In addition, HTC Vive is now compatible with Oculus's VR games, which allows Vive's user have more optionality in VR content.

- **Channel Strategy:** HTC Vive's channel strategy is to focus on both B2B and B2C. In addition, the company also offers Vive to Internet cafés (in partnership with Shunwang Technology in China) and amusement parks.

**Figure 16. Samsung Gear VR**


Source: Samsung Electronics

**Figure 17.Microsoft HoloLens**

Source: Microsoft

## Samsung Gear VR

Samsung Electronics announced its Samsung Gear VR in September 2014 and began selling models for developers in December last year. Samsung introduced new models in March 2015, with the release for the general public in November of that year. Gear VR has been developed in collaboration with Oculus. It is used in conjunction with some models in Samsung's Galaxy line of smartphones. The headset can be used wirelessly. The device will offer Netflix, Vimeo, Hulu, and other content. Affordably priced at $99, it is likely to be positioned as introductory VR equipment. The new models announced and launched in August are compatible with Samsung's new Galaxy Note 7 smartphone and will cost $99.

## Microsoft HoloLens

Microsoft announced Microsoft HoloLens in January 2015 during a Windows10 press event. The company released a developer model in March 2016, priced at $3,000. HoloLens is an independent goggle-type computer equipped with multiple sensors to detect outside world information and equipped with a lens for displaying holograms (similar to a projector). Demo versions allow users to play Minecraft, Halo, and other games with real world objects treated as virtual objects. In addition to games, the equipment has been shown in demo sessions to be compatible with various simulations and graphics-rich applications.

**Figure 18. Intel Project Alloy**

Source: Intel

## Intel Project Alloy

Intel announced a device dubbed Project Alloy at the Intel Developer Forum in August 2016. Alloy is an all-in-one head-mounted display incorporating all the elements needed for VR, including a CPU, sensors, camera, and battery. What sets the device apart is that it does not need to be connected to a high-end PC, and can be used completely wirelessly. The inclusion of a RealSense camera means the device can detect hand movements, enabling the user to control objects in the VR environment and to be blended into the VR environment in real time. Intel dubs this experience “merged reality”. Intel partners with Microsoft, and Project Alloy uses the Microsoft Holographic platform. By making Alloy open source, the firm hopes that original equipment manufacturers (OEMs) will launch Alloy-based products in the second half of 2017.

Other VR/AR-related companies are ramping up activity with each passing day. We have seen large capital procurements with the intention of starting up a business within the next several years.

**Figure 19. VR/AR Timeline**

| Year | Mon | Event |
|---|---|---|
| 2012 | Apr | Google announces Project Glass |
| | May | Leap Motion procures $12.75 million, launches Leap Motion controller |
| | Jun | Oculus launches test model |
| 2013 | Mar | Oculus Rift DK1 launched |
| | Apr | Google Glass developer model launched |
| 2014 | Feb | Magic Leap procures $50 million from Google |
| | Mar | Facebook acquires Oculus for $2bn |
| | | Sony announces Project Morpheus |
| | May | Consumer version of Google Glass launched |
| | Jul | Oculus Rift DK2 launched |
| | Sep | Samsung Gear VR announced |
| | | Samsung Gear VR developer model launched |
| | Oct | Magic Leap procures $542 million from Google and Qualcomm |
| 2015 | Jan | Google Glass sales suspended |
| | | Microsoft announces Microsoft HoloLens |
| | Mar | Sony announces new format for Project Morpheus |
| | | HTC announces the HTC Vive |
| | Jun | Consumer version of Oculus Rift announced |
| | | FOVE procures capital from Samsung Ventures (amount undisclosed) |
| | | Starbreeze acquires InfinitEye, announces Star VR |
| | Sep | Sony announces the launch of PlayStation VR as part of Project Morpheus |
| | Oct | Facebook CEO Mark Zuckerberg notes the firm is working on AR (at Vanity Fair New Establishment Summit) |
| | Nov | Next VR procures $30.5 million from Comcast Venture and Time Warner Investments, among others |
| | Dec | Samsung Gear VR consumer model launched |
| 2016 | Mar | Oculus Rift consumer model launched |
| | | Microsoft HoloLens developer model launched |
| | Apr | HTC Vive consumer model launched |
| | Jun | Microsoft announces new format for Microsoft Xbox "PROJECT SCORPIO" adopting VR |
| | Aug | Intel announces Project Alloy |
| | Oct | PlayStation VR launch expected |
| | H2 | Meta2 (AR device) developer model to be launched |

Source: Company data, Citi Research

## Content Shooting Camera and Motion Capture Devices

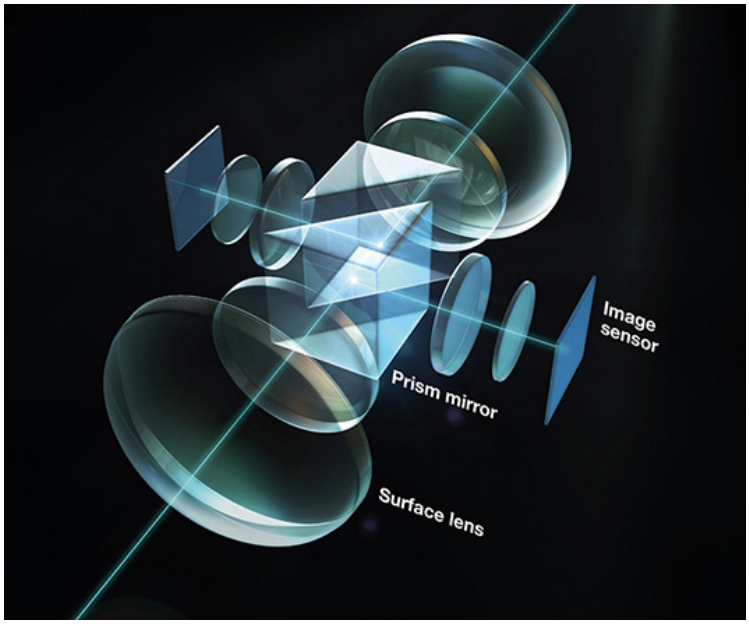
Environment for 360 degree images (omnidirectional shooting)

One purpose of the VR head mounted display (HMD) is to create the feeling of being immersed in a virtual world. In addition to VR that consists entirely of computer graphics, like in a video game, HMDs can display real image content. The HMD wearer has a 360-degree viewing angle, which creates a real world experience. Many cameras that can handle this kind of content have been released. Ricoh's Theta series and Samsung's Gear 360 are able to do so without any special operation or editing. VR diffusion could be a tailwind for these products.

The Ricoh Theta can shoot 360-images independently

Ricoh unveiled the first Theta in September 2013 and released it in Europe and the U.S. in October and Japan in November of that year. The latest model, the Theta S, was released in October 2015, and is 44mm wide, 130mm high, and 22.9mm deep (including the lens), and weighs 125g. The Theta combines images shot through fisheye lenses at the front and rear of the camera to create a full spherical image. A 1/2.3-inch, 12MP image sensor is located on the surface of the camera to minimize the thickness and size of the body. This is a major feature of the Theta and helps to minimize boundary misalignment when the two images are combined.

**Figure 20. RICOH THETA S: A Signature Optical Design with an Imaging Sensor Located on the Surface**




Source: Ricoh

GoPro could be adapted using peripheral equipment to take 360-degree images

Since releasing its first camera in 2004, GoPro has focused on basic compact models that do not include a zoom or other features. The latest HD Hero series has captured the top share of the action camera market. It has proved popular because it allows users to take impressive photos while playing sports or performing outdoor activities and because it is suitable for taking selfies, a growing market. Shipments increased from 1.14mn units in 2011 to 6.6mn units in 2015. Cumulative GoPro shipments have reached around 22 million units in mid-2016.

GoPro is widely used to shoot 360-degree images. Unlike the Ricoh Theta, however, the GoPro has the same field of view as a normal camera. Consequently, spherical images are generally created by using several GoPros to shoot an image at the same time.

Also, fisheye lenses and other peripheral devices can be used to extend the functionality of the GoPro so that a single action camera can shoot something that approaches a full spherical image. If VR content could be easily produced by anyone, then we would expect VR device penetration to accelerate.

**Figure 21. Fisheye Lenses for the GoPro HERO**


Source: Entaniya

## Motion Capture Critical to Future of VR/AR

Wearable sensors that relay body movement

VR/AR will enable users to look at a virtual world and computer graphic objects using the display, but it may also be possible in the future to touch, manipulate, and move objects. In addition to the headset, this will require the use of sensors on the body and hands in order to communicate the body's movement to the computer. To do this, users will wear gloves with sensors and devices with actuators (haptic devices) that can relay the sense of touch. These are so-called wearable devices. If all that is required is to recognize movement in a room or the movement of hands in front of the user's body, then sensors that use cameras (image sensors) and infrared sensors could be placed in the corner of a room or in front of the user's body to measure movement.

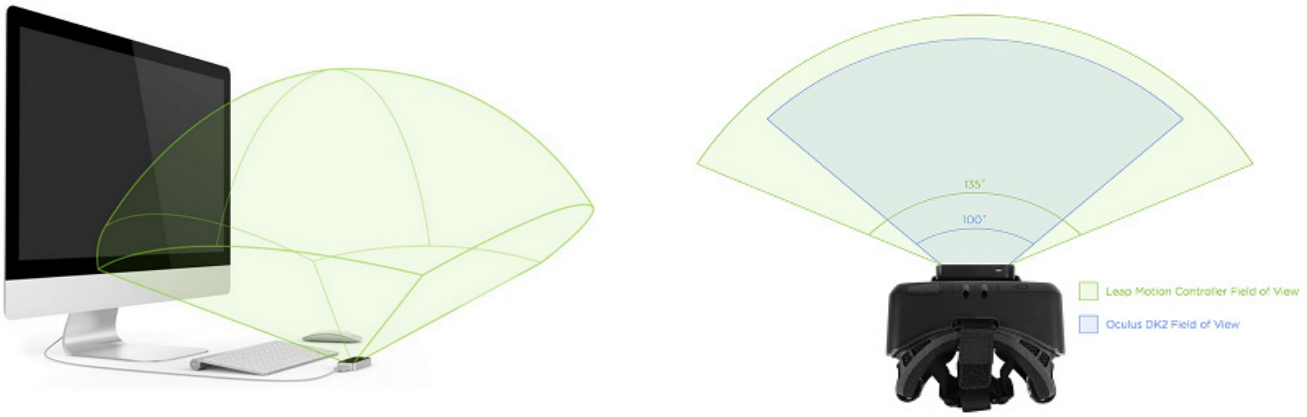
We do not specifically factor volumes or values for these peripheral devices into our industry forecast model. However, once VR/AR headsets that enable a more immersive experience are developed and computer processing capacity increases, there will be demand to be able to touch objects and be touched in the virtual world. Here we outline a range of such devices.

Leap Motion: VR-related

The U.S. venture company Leap Motion launched a compact sensor device, also named Leap Motion. This enables a user to move both hands in the space covered by the sensor, which will recognize the movement and perform a range of tasks on the PC monitor. If a user starts up Google Earth and moves his hands with Leap Motion, he can move on the screen as though he is flying around a town in the sky.

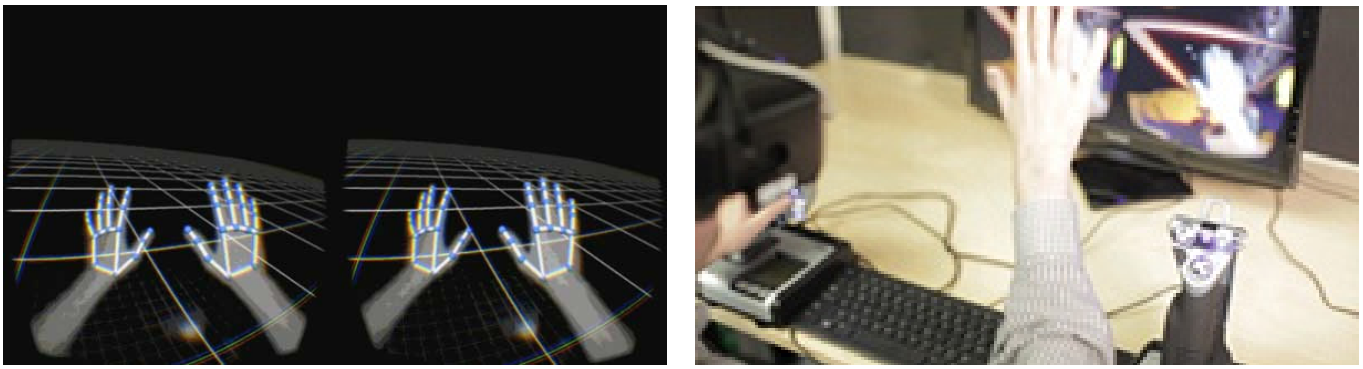
If this sensor were mounted on a VR headset (Oculus Rift) and connected to VR, there would be many future possible uses. By establishing the sensor recognition region in the area in front of the user's eyes at the same time that the sensor recognizes the movement of hands held in front of the body, the virtual world created by VR would align with the movement of the head and also show the user's hands. Thus, the hands in the VR display would move just as if they are the user's own hands.

**Figure 22. Leap Motion Sensor Recognizes Space**




Source: Leap Motion

**Figure 23. Using Your Own Hands in VR with Leap Motion**



Source: Leap Motion

Xbox Kinect: VR-related

While the recognition accuracy of Kinect, which was launched in 2010 and drove sales of the Xbox 360, is lower than Leap Motion, it was also the first to introduce a mechanism to track human joints. It detects human movement using image sensors and infrared sensors. The information collected is then displayed as CG on a screen.

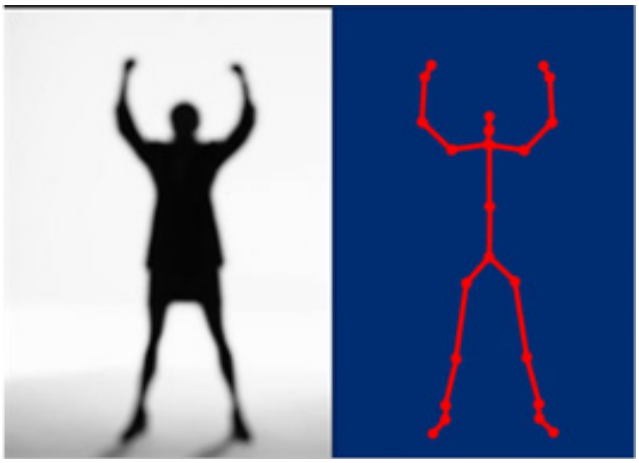
Kinect was initially announced under the name Project Natal in June 2009 and attracted much attention. Launched in November 2010, sales were very strong. Cumulative sales have now reached than 10 million units, and the next generation Kinect for the next generation Xbox One is now on sale.

Kinect is a device that is highly compatible with VR, and we think Microsoft will use it as a technological base point when expanding its business in the VR area. VR will be used mainly within only a limited range of portability or no portability at all, so detecting a user's movement using a fixed sensor device such as Kinect will be effective. We do not specifically factor Kinect into our market model, but we think this mechanism of sensing movement within an overall space and displaying it in a virtual space is a promising component of VR.

**Figure 24. Kinect**

Source: Microsoft

**Figure 25. Kinect Detects Motion by Scanning Joints**



Source: Citi Research

## VR/AR and PCs

### CPU, Display, and Battery: The Common Technological Issues

VR will require $1,000 PCs

Whether market penetration of VR/AR increases greatly will depend on technological progress. It is particularly important for the initial cost to come down. For VR, the cost of the headset is likely to be around $450, and it will be necessary to connect it to a high-end PC costing about $1,000. This is because a high-performance graphics card will be necessary to process the CG that is projected onto the VR headset display.

There are few problems associated with connecting the VR headset with a cable to a PC, but reducing the total cost will be critical to increasing market uptake, and the cost of buying the PC cannot be ignored. We would not expect significant uptake of VR by the consumer market if the combined cost of the high-end PC and the headset was in excess of $2,000.

In the case of AR, mobility is the key to market uptake. For this, the performance of the semiconductors and other electronic components in today's smartphones would be ample for the key components in AR headsets, but reducing power consumption is the critical determinant of mobility.

PS4 already provides hint to solution of cost problem

We are optimistic regarding the cost problem. In the technology world, innovation has repeatedly reduced the cost of realizing the required functionality and performance. In addition, the PlayStation4 will be used as the CG processing computer for the PlayStation VR headset to be launched in 2016, and the price cut in 2015 means that a machine with 1,830GFLOPS (single precision) of processing power can bought for $349.

Figure 26. Sony PlayStation 4

Source: Sony Interactive Entertainment Inc.

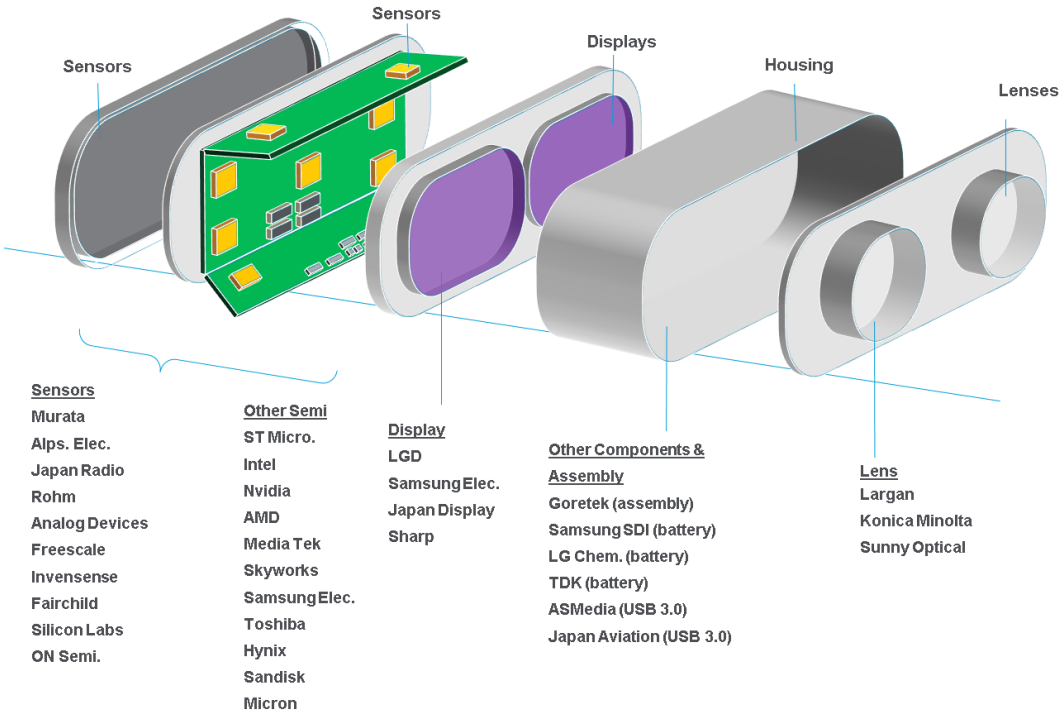
## Teardown and Bill of Materials (BOM) Analysis

VR goggles are necessary hardware for the VR environment

The necessary hardware for a VR environment includes a terminal in the form of goggles, a computer for data processing, and network equipment. Looking ten years or more into the future, we expect data processing computers to be incorporated into the viewing goggles. We also expect to see standalone devices that require no network connection.

Goggle-type headsets use two small displays (one in place of each of the goggle lenses) and an array of sensors, including acceleration sensors, angular velocity sensors, electronic compasses, image sensors, and others.

Figure 27. VR Headset Teardown




Source: Citi Research

Displays require high refresh rates

Users look into VR goggle displays at close range, as if looking into a kaleidoscope tube. Displays used in the left and right goggle sockets are either organic EL displays or LCDs. They must have very high resolution and high refresh rates. It is also important for the two displays to be perfectly synchronized. Displays in use today have a resolution of 386ppi or more and use refresh rates of 60~120Hz.

Better sensors than those used in smartphones

The main sensors mounted on VR goggles include an acceleration sensor, an angular velocity sensor (gyro), and a geomagnetic sensor (or electronic compass). Others include proximity sensors, ambient light sensors, image sensors, and inertial sensors. The acceleration sensor supplies information about orientation and movement, while the angular velocity sensor detects inclination and rotation. The geomagnetic sensor determines compass direction and detects changes in the direction the user faces.

Acceleration, angular velocity, and geomagnetic sensors are common in smartphones, along with GPS units, but virtual reality headsets are generally used indoors in a fixed position, so they do not require GPS input.

VR experiences rely more directly on the senses (vision, hearing) than do smartphone screens, and, for that reason, the sensors used in VR equipment must be of higher quality than the sensors used in most smartphones. Gear VR, marketed by Samsung Electronics, relies on the sensors and display built into a smartphone to create a VR experience. Products developed and announced by Sony, Oculus, and NVIDIA create VR experiences using the 120Hz PS and other equipment several times more sophisticated than the average smartphone.

Some users experience VR sickness

In some people, VR systems can cause an unpleasant sensation known as VR sickness. High-resolution displays, fast refresh rates, precise synchronization, high-precision sensors, and fast reaction times are all important tools to help ameliorate VR sickness. The success of virtual reality depends to a large degree on the technological level of the electronic components and devices used.

What can we do with VR?

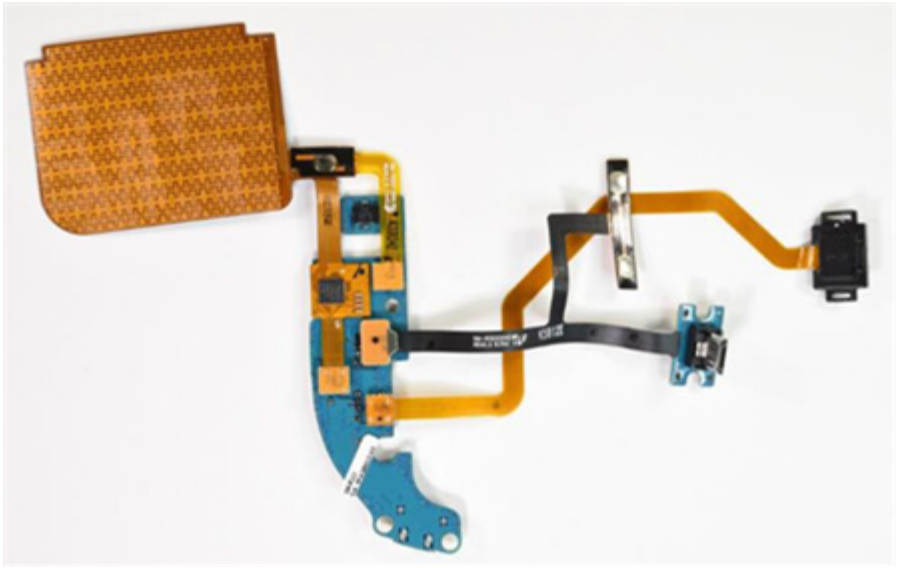
The key characteristic of VR is that users truly feel as if they have placed themselves in a virtual space. By viewing high-resolution computer graphics in 3D, users are enveloped in a sense of reality that differs from the feeling of “really being there” or of a powerful performance. This is generally known as immersion. By drawing users into virtual spaces and information, the experience is changed into one in which playing games or watching movies become highly immersive activities. This has lots of applications in the commercial sphere alone, and we expect ramp-ups to be relatively rapid in areas such as remote medicine, military drills and pilot training, and simulators for auto driving instruction.

## Analysis and Breakdown of VR Headsets

Samsung Gear VR attaches Samsung Galaxy phones to the front of the headset

Samsung Gear VR was launched in November 2015. It is used by attaching select models of the Samsung Galaxy smartphone series to the front of the headset. Graphics processing and the sensing of headset movement is done by the application processor (AP) that is used in almost all smartphones. As a result, few electronic components are required in the headset itself. The only components on the printed circuit board are the microcontroller, an accelerometer/gyro sensor, and five connectors, which are connected to a touch panel, a USB port and buttons. Other than the electronic components, the main parts are a plastic frame and cover and a lens that magnifies the display.

**Figure 28. Components Used in Samsung Gear VR**



Source: Fomalhaut, Citi Research

The Oculus Rift DK2, which was announced in March 2014 and released in July of the same year, is modeled on the Oculus Rift that is designed for developers. In late March 2016, the Oculus Rift for consumers was released, and the DK2 was taken off the market. The design appears to differ little from the consumer model. The Oculus Rift needs a wired connection to a high-end PC that is responsible for graphics processing and other functions.

Wearability is dependent on factors other than weight

The 440g Oculus Rift DK2 is attached to the head with a rubber strap. At 470g, the consumer model is slightly heavier than the DK2, but is feels lighter when actually worn. The consumer model uses a similar rubber strap to support the headset from the back of the head, but a different design for the strap on the back is probably what makes it feel lighter.

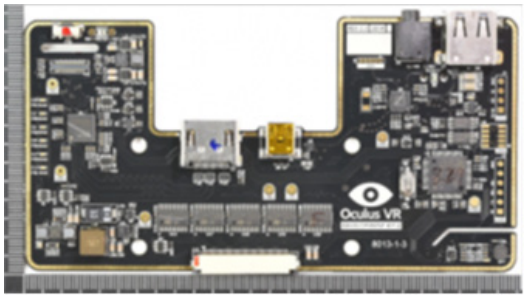
**Figure 29. Oculus Rift: Overview of Mass Market Model**

Source: Oculus

Oculus Rift has more components than the Gear VR

Unlike the Gear VR, the Oculus Rift contains a larger range of electronic components, starting with the graphics display and infrared light-emitting diodes (LEDs) that sense the movement of the headset (in other words, the movement of the user's head). The display is a 5.7" organic EL display. The resolution is 1,920 x 1,080, and is the same display as used in the Samsung Galaxy Note 3 smartphone (so it includes the touch panel, unnecessary in this particular use case). The refresh rate is 75Hz.

**Figure 30. Oculus Rift DK2: Many Components on Main Substrate**



Source: Fomalhaut, Citi Research

**Figure 31. Oculus Rift DK2: Display**

Source: Fomalhaut, Citi Research

**Figure 32. Oculus Rift DK2: Infrared LEDs All Over Headset (left), Special Infrared LED Formation on Flexible Printed Circuit (FPC) (right)**

Source: Fomalhaut, Citi Research

HTC Vive allows for user movement

The HTC Vive was announced at the March 2015 Mobile World Conference, and released in April 2016. The design differs little from the Oculus Rift. The HTC Vive also requires a wired connection to a high-end PC that is responsible for graphics processing and other functions.

One characteristic of the HTC Vive is that it enables the user to move about a 5m x 5m space while wearing the head mounted display. In addition to moving around while wearing the head mounted display, the user can also perform actions such as swinging a sword in the VR space using a handheld controller. The Gear VR headset itself does not require a connection to a PC, so the player is able to move about. However, much of the available content requires the use head movements and the touch panel on the side of the headset, and little content is designed to require the user to move about. The actions of the user are restricted by the wired connection to a PC for the Oculus, and the infrared sensors work over only a limited distance, so it too is not designed for the user to move about.

**Figure 33. HTC Vive: Infrared LEDs on Base Station, Detects LEDs on Headset**

Source: Fomalhaut, Citi Research

**Figure 34. HTC Vive: Controller, Like Headset, has Infrared Sensors**

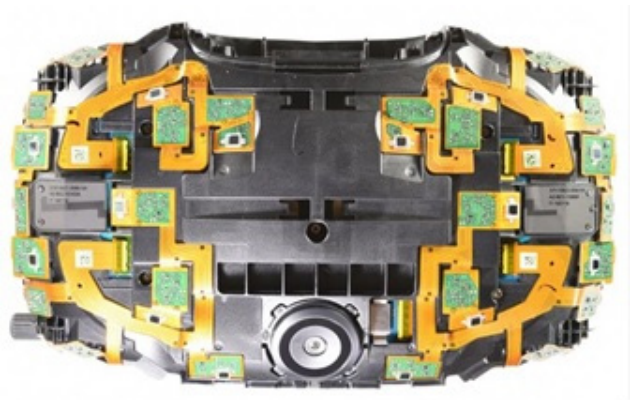
Source: Fomalhaut, Citi Research

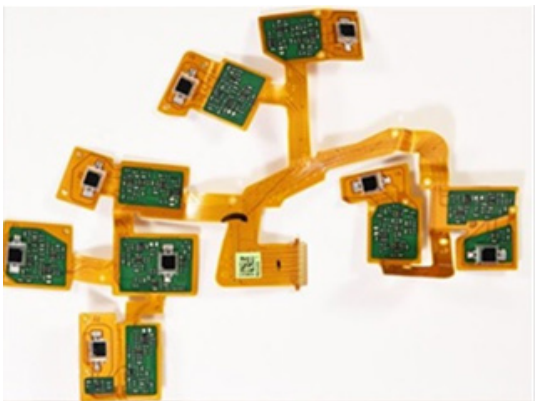
Differences in motion tracking

The HTC Vive also incorporates a large number of electronic components, but one difference to the Oculus Rift is the large number of infrared sensors. The Oculus Rift tracks motion using a camera in front of the user that senses the infrared from the headset, but the HTC Vive tracks motion with sensors on the headset that sense the infrared emitted by LEDs on the base station (Figure 35).

There are four flexible printed circuits (FPCs) on which these infrared sensors are mounted: two each of two types of FPC, and each one is smaller than those used in the DK2. Similar to those of the Oculus Rift DK2, the FPCs are of very complex shapes, and by themselves account for 15% of the cost of the HTC Vive, so they add considerably to the cost of manufacturing.

**Figure 35. HTC Vive: Infrared Sensors All Over Headset (left), FPC Sporting Infrared Sensors (right)**





Source: Fomalhaut, Citi Research

**Figure 36. Comparing Major VR Headsets**

| | PlayStation VR | Oculus Rift DK2 | Oculus Rift | Gear VR | HTC VIVE |
|---|---|---|---|---|---|
| Manufacturer | Sony | Oculus (Facebook) | Oculus (Facebook) | Samsung + Oculus | HTC Corporation |
| Release | Oct 13 2016 | Jul 29 2015 | Mar 28 2016 | Nov 20 2015 | Jun 01 2016 |
| Price | $399 | $350 | $599 | $99 | $799 |
| System requirement | VR + Camera + PS4 | VR + Camera + PC | VR + Camera + PC | VR + Smartphone | VR + Camera + PC |
| Size (mm) | 187 x 185 x 277 | 188 x 105 x 127 | 171 x 102 | 198 x 116 x 90 | 191.4 x 116.6 x 121.5 |
| Weight (g) | 610 | 440 | 470 | 318 | 566 |
| Display (Supplier) | Organic light-emitting diode (OLED) | OLED (Samsung) | OLED | - | OLED |
| Resolution | 960*1080 x2 | 1920 * 1080 | 1080 * 1200 x2 | - | 1080 * 1200 x2 |
| Refresh Rate | 120Hz | 75Hz | 90Hz | - | 90Hz |
| Processor | NA | STM STSW-STM32100 32-bit, 32MHz | STM STM32Fo72VB 32-bit, 48MHz | STM STM32F401 32-bit, 84MHz | STM STM32F072R8, 32-bit, 48MHz |
| Motion Sensor | Accelerometer, Gyro | Accelerometer, Gyro | Accelerometer, Gyro | Accelerometer, Gyro | Accelerometer, Gyro |
| Ambient Sensor | Proximity | Proximity | Magnetometer | Proximity | Light, Proximity |

Source: Company materials, Citi Research

**Figure 37. VR Headsets BOM Analysis**

| (in USD) | Oculus Rift DK2 | Oculus Rift | Gear VR | HTC VIVE |
|---|---|---|---|---|
| Cellular | 0.00 | 0.00 | 0.00 | 0.00 |
| WLAN/BT/NFC | 0.00 | | 0.00 | 2.20 |
| Processor + Memory | 10.00 | 3.75 | 10.00 | 12.90 |
| Controller | 10.20 | 7.94 | 0.00 | 8.30 |
| Motion Sensor | 32.15 | 4.87 | 0.80 | 1.25 |
| Ambient Sensor | 0.40 | | 0.40 | 1.46 |
| Touch Pad/Panel + Controller | 4.40 | | 2.40 | 0.00 |
| Camera | 5.34 | | 0.00 | 6.21 |
| Display | 35.00 | 69 | 0.00 | 40.00 |
| Quartz | 0.27 | 1.00 | 0.11 | 1.08 |
| PCB | 4.76 | 22.5 | 0.88 | 4.77 |
| FPC | 2.00 | 24.09 | 1.20 | 36.66 |
| Connector + Port | 2.74 | | 0.90 | 2.39 |
| Case | 18.15 | | 21.50 | 53.15 |
| Lens | 24.00 | 25.00 | 24.00 | 24.00 |
| Passive Parts | 1.05 | 4.03 | 0.16 | 5.54 |
| Others | 5.80 | 2.38 | 0.00 | 40.59 |
| **Total** | **156.26** | **138.56** | **62.35** | **240.50** |

Source: Formalhaut Technosolutions, iFixit, Citi Research

## Semiconductor, Display, Sensors, and Connectors Analysis

Computer gaming is one of the largest entertainment markets. Growth in the market is expected through: (1) the launch of new gaming titles; (2) the rise of eSports; (3) increasing realism of visual graphics; and (4) virtual reality. NVIDIA's graphics processing units (GPUs) improve the visual quality of graphics, increase frame rate, and improve realism in gaming through the utilization of 3D software and algorithms. NVIDIA's strategy in gaming "is to use advanced graphics technologies to create a range of gaming platforms, stretching across PCs, mobile devices, and the cloud."

PC is the most targeted gaming platform

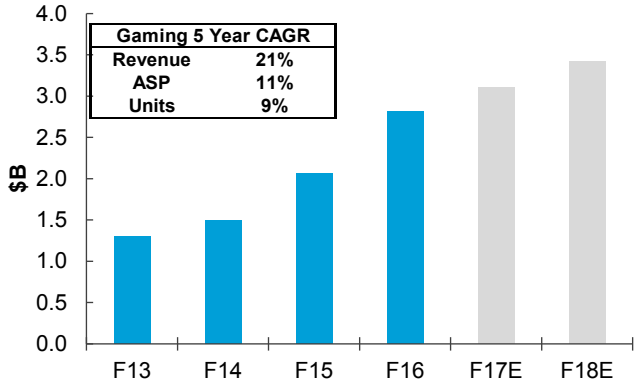
The gaming market is a $100-$120 billion market, including software and hardware, and is growing fastest in emerging markets. PC is the most targeted platform, followed by mobile, PlayStation 4 and Xbox. NVIDIA's current installed base is roughly 100 million users (60% of which are in the developed world). Approximately 80% of that installed base is using systems below the recommended GPU class. NVIDIA estimates that there are approximately 200 million gamers that are using sub-par PCs that are targets for new or higher power NVIDIA GPUs.

NVIDIA's products for the gaming market include: GeForce GTX GPUs for PC gaming, the SHIELD family of tablet and portable devices for mobile gaming, GRID for cloud-based streaming on gaming devices, and GameWorks development services for gaming platforms. NVIDIA's GPUs range in average selling price (ASP) from $99 to $1,000.

NVIDIA's GameWorks is an investment into the developer community. NVIDIA's engineers develop renderings of real world effects – smoke, fire, water, physical interactions — onto a GPU and create software libraries that become integrated into the top gaming engines.

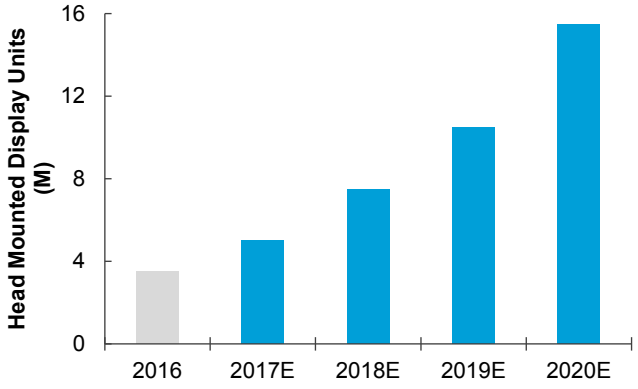
NVIDIA's GeForce is also an investment into the gamers themselves. The GeForce product line has two major features. First, it keeps the gamer's PC always updated – NVIDIA engineers work months in advance of a game launch to ensure that the software drivers within the GPU are updated, tuned, and ready for the new game; a process known as Game Ready. Second, when a gamer installs a new game, the GeForce experience will configure that game for the specific hardware via one-click optimization.

**Figure 38. NVIDIA Gaming Revenue**




Source: Citi Research

**Figure 39. NVIDIA VR Opportunity**



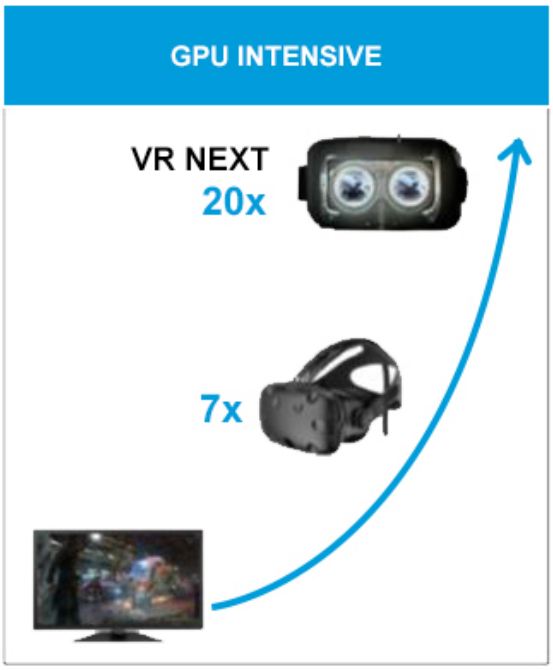

Source: Citi Research

According to NVDIA, VR gives users a new way to interact with PC, content, and each other. VR is not going to be just about gaming or battlefield in a head-mounted display; it's going to be a new way to interact with characters in the environment, movies, or even professional use cases, such as IKEA's latest VR app that uses NVDIA graphics for designing rooms and homes in IKEA furniture. It allows consumers to paint, set up equipment, and look inside their virtual rooms.

NVIDIA's VR strategy extends outside the scope of gaming

While VR opportunity or ramp is difficult to predict near-term, NVDIA believes a hockey stick-like penetration will occur over the next 4-5 years. For VR, the frame rate has to be much higher than standard gaming frame rate. One can game at 30 frames per second, which some consoles do, but one cannot take VR at 30 frames per second. VR requires 90 frames to 120 frames per second. NVDIA roadmap calls for 4K, 8K, 16K headroom to drive the future of VR which will a lot more horsepower or GPU intensity.

Figure 40. GPU Intensity to Increase Exponentially for VR




Source: NVIDIA

Improvement in GPU performance key to market uptake of VR/AR

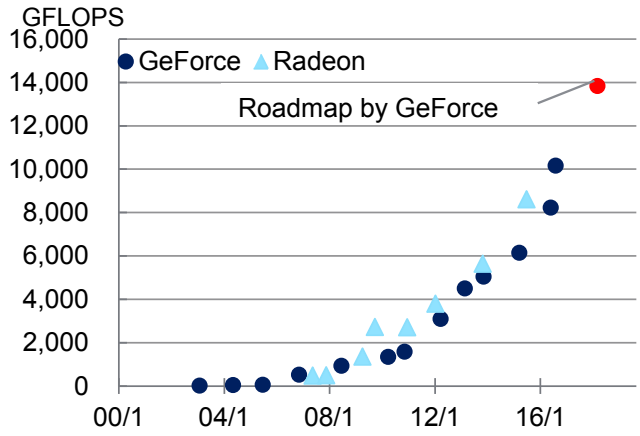
We think that in the future all necessary functions for VR and AR will be built into the headset. But during the transition period over the next 10 years, the speed of CG processing by the GPU and other components and the extent to which power consumption can be reduced will be important. Our analysis concludes that technological development will be insufficient in the next 10 years for the GPU processing capacity necessary for VR to be powered by a battery. Nevertheless, the cost of a PC to connect with using a cable will fall sufficiently.

For the graphics card that contains the GPU to have the recommended specifications, a product costing around $500 is currently necessary, but this could fall to $50 over the next 10 years.

Reduction in AP and MCU power consumption are key to market uptake of AR

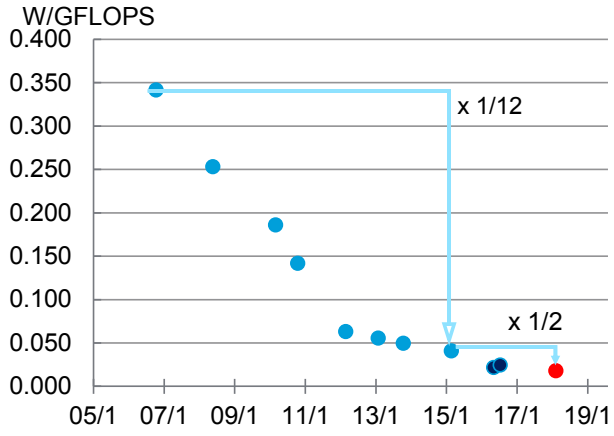
For the power consumption issue critical to AR, the applications processor (AP), which also functions as a graphics processor, and the microcontroller unit (MCU) are important. Right now power consumption for the digital signal processor is about 50mW, but we note that power consumption fell by 99% between the 2000s and 2010s. If there is another 99% drop over the next ten years, these components could be built into the headset and powered by a battery for a sufficiently long time. This would create the mobility that would provide a powerful driver of AR market uptake. Power consumption for PC GPUs fell by 92% over the last ten years, and could fall by another 50% by around 2018.

Figure 41. GPU Performance Evolution




Source: NVIDIA, AMD, Citi Research

Figure 42. GPU: Power Consumption Relative to Performance




Source: NVIDIA, Citi Research

## European Semiconductors for GPU and MCU

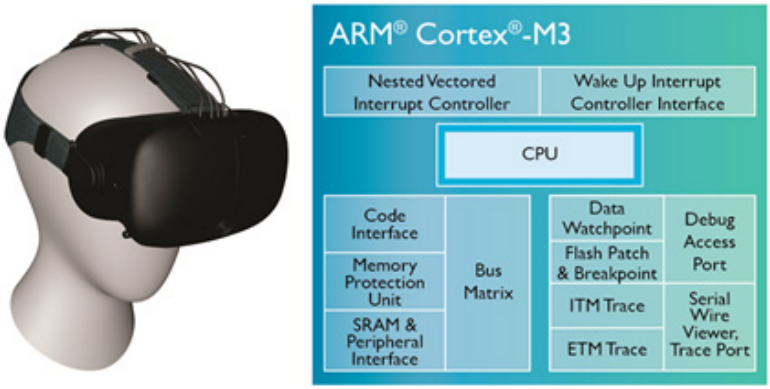
**Amit Harchandani**
Head of European Technology Research Team

We view ARM, Infineon and STMicroelectronics as the most exposed names to the virtual and augmented reality within the European semiconductors space. Over time, we see applications software companies such as SAP benefiting the most as the new VR/AR interface increases the value of the enterprise apps. Meanwhile, on the IT services side, we see opportunity in terms of technical expertise needs that should benefit companies like Capgemini and AtoS.

### ARM Holdings

– **Exposure to VR/AR:** ARM is exposed to VR/AR theme primarily through the controller chip, either in the form of an ARM-based MCU used in the a VR/AR headset to process data collected via an array of sensors (e.g. ARM Cortex-M3-based MCU used inside the Oculus Rift), or in the form of a more powerful ARM Cortex-A-based application processor needed to provide advanced computing power in AR headsets (e.g. ARM Cortex-A9-based TI OMAP 4430 application processor used inside the Google Glass).

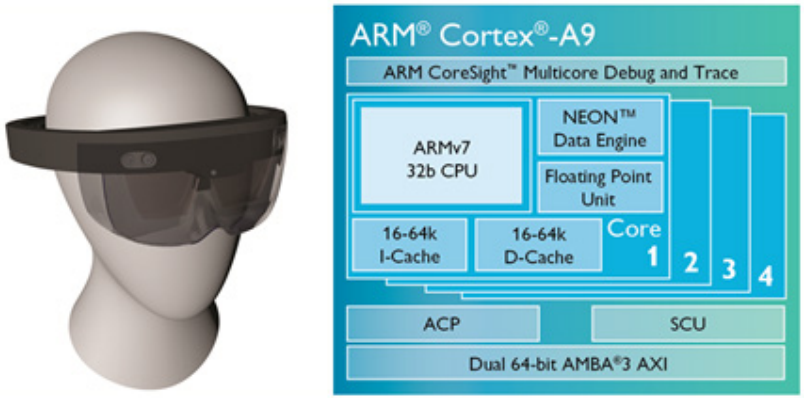
Figure 43. We See VR Headsets Using Controllers Based on ARM Cortex-M Processors, such as the M3 Powering the Oculus Rift




Source: Company data, Citi Research

– **ARM is investing in Mali to meet requirements to deliver the VR experience:** These include low latency (via minimization at each stage of GPU rendering pipeline and extensions for interfaces such as OpenGL), high frame rate (reduction of bandwidth via compression, multi-view extensions) and high resolution (scalable GPUs with multiple cores). More broadly, we gather that ~500 engineers are working on Mali, which we estimate represents ~15% of the total engineering workforce.

**Figure 44. We see AR headsets Using Application Processors Based on ARM Cortex-A, Such as the A9 based AP Used Inside Google Glass**




Source: Company data, Citi Research

Power efficiency is critical for AR mobility

– **We see upside from AR:** ARM forecasts total cumulative VR shipments of 56.8 million units by 2018, based on adoption by three groups – hardcore gamers, light gamers, and kids. We calculate this implies shipment of ~23.5 million units in 2018, with the revenue opportunity cited at ~$2.3 billion in 2018. In our view, ARM should benefit from the need for advanced computers in AR. An important feature of AR is mobility, making power-efficient computational ability a critical determinant. We see ARM as being well positioned to emerge as the architecture of choice.

■ **STMicroelectronics:**

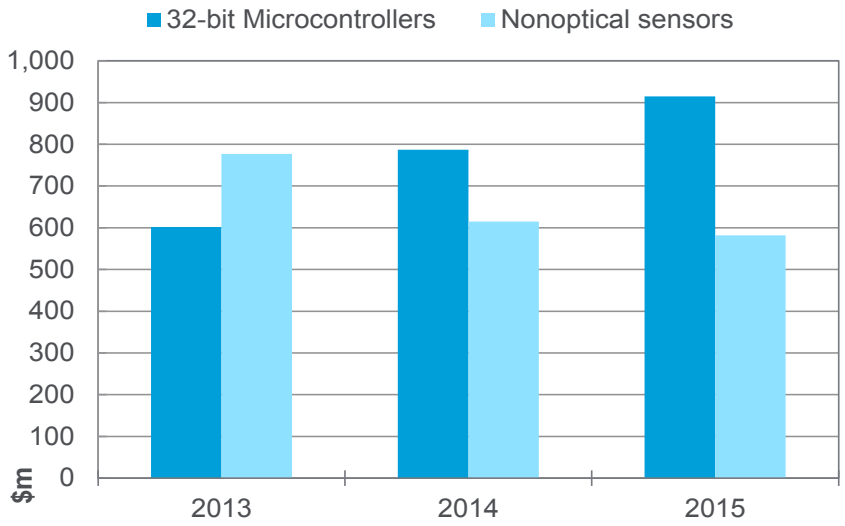
– **Exposure to VR/AR:** STM is exposed via its broad portfolio including both optical and non-optical sensors, microcontrollers, and power semiconductors.

– **In particular, we highlight the firm's microcontroller wins so far.** According to teardown data published by Japanese firm Fomalhaut Techno Solutions, we understand that controllers used in both Oculus Rift and Samsung Gear VR were based on STM's 32-bit microcontrollers. In addition, we also note that parts included additional content in the form of memory modules and power management content.

– **We note the tough competitive dynamics in case of MEMS sensors.** While STM manufactures a broad array of sensors, we note that the firm has lost share in non-optical sensors, particularly on the micro-electromechanical systems (MEMS) side over the past 2 years, reflecting tough competitive dynamics – the Oculus Rift, for example, uses accelerometer and gyroscope provided by rival firm InvenSense. We understand that the Samsung Gear VR meanwhile uses components from Bosch.

– **STM could also provide additional sensors used in AR.** On the optical sensors side, we see potential for adoption in AR headsets of STM's image sensors based on time of flight (TOF) principle that are used to enable spatial/3D measurement. STM also makes GPS and other connectivity sensors – the Google Glass for example used GPS Transceiver from CSR (now part of Qualcomm).

**Figure 45. STM Revenue Trends: 32-bit MCU vs. Nonoptical Sensors**




Source: Gartner, Citi Research

**Infineon:**

– **Exposure to VR/AR:** although Infineon does not boast of similar breadth in terms of its motion MEMS portfolio as STM in our view, we still see it benefiting through image sensors and to a lesser extent potential adoption of MEMS microphones. Going forward, we see Infineon further benefiting through rising adoption of power semiconductors to drive energy efficiency, particularly for AR headsets.

Time-of-Flight technology provides realistic 3D data

– **Infineon's 3D image sensors are used in Google's Project Tango.** 3D image sensors are used to enable spatial/3D measurement, as well as indoor navigation. Infineon's latest 3D image sensors (developed in partnership with fellow German firm pmdtechnologies and part of the REAL3) were demonstrated at CES earlier this year, with volume production beginning in the first half of 2016. We note one of these chips has been used in Google's Project Tango. The goal of Project Tango is to give mobile devices a human-scale understanding of space and motion. To achieve this, the 3D Time-of-Flight technology is utilized alongside motion tracking and an RGB camera to sense the 3D environment in real-time and to provide such realistic 3D data.

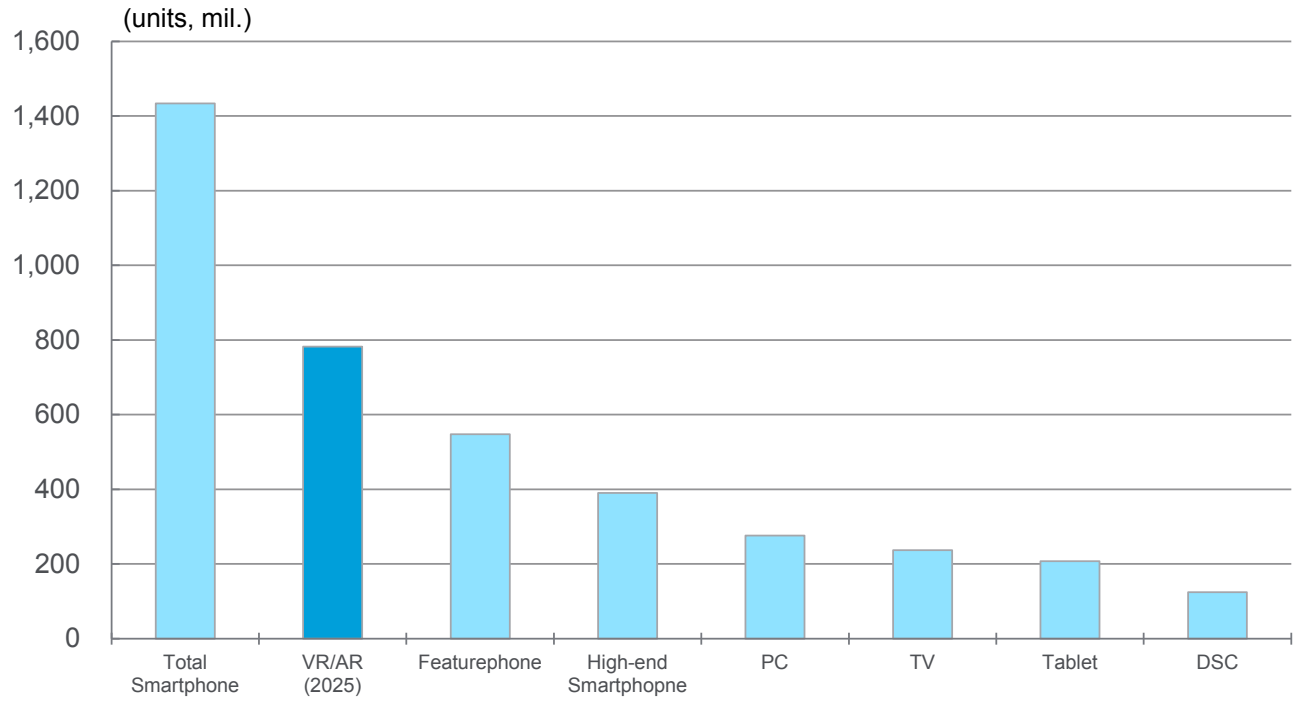
– **Rising adoption of power semiconductors, particularly for AR should help.** As noted earlier, supporting high-level image processing over extended periods of time in the case of AR headsets requires very high-capacity batteries and batteries of a high energy density. The ultra-high-performance components and semiconductors required are not yet available with current technology. Therefore, we believe Infineon, given its leadership position in power semiconductors, should emerge as vital enabler as well as beneficiary of AR.

## Display for VR/AR

Is VR/AR the next hope for display industry?

As we discuss below, if the VR/AR headset market grew to 300 million units, the market for the displays used would be 600 million units. If high-end smartphones currently account for 390 million of the overall smartphone market of 1.4 billion units, then the VR/AR headset display market would be larger than the current high-end smartphone display market.

**Figure 46. LCD Panel Market by Major Application**




Source: Citi Research

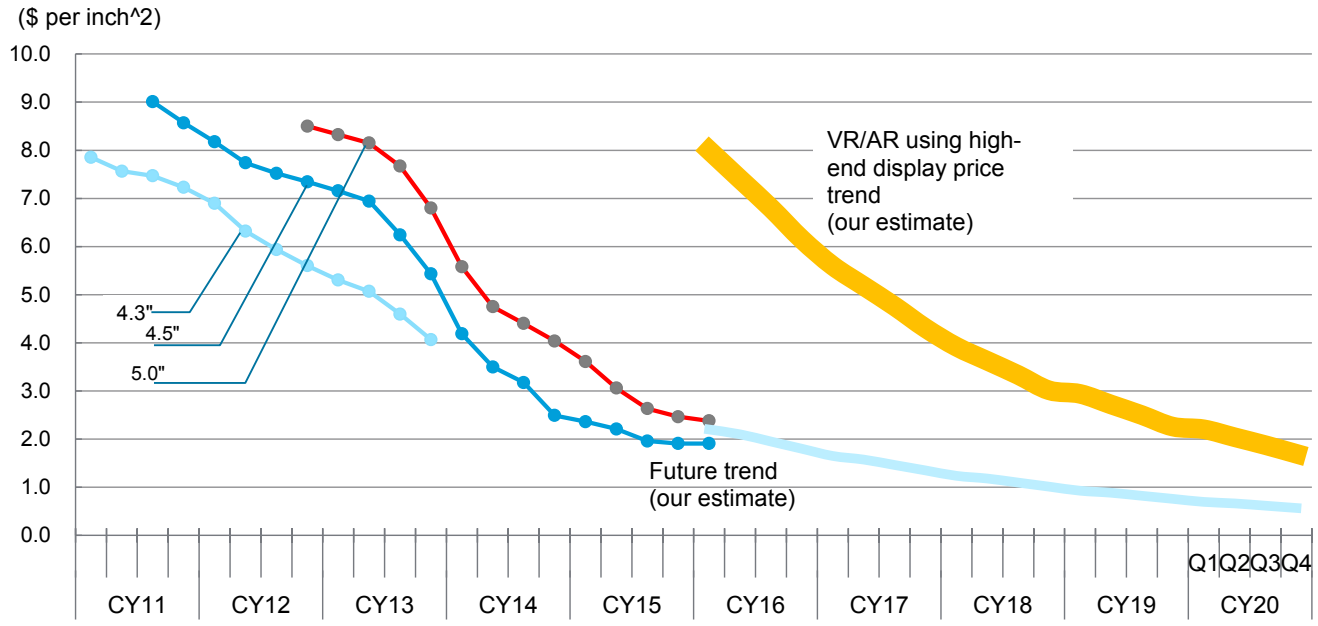
( Note: VR/AR Figure is for 2025; the rest are 2015 estimates.)

There is ample room for development of VR/AR displays

The displays currently used in VR/AR do not fully satisfy requirements. For VR, LCDs or OLED displays are used. Only a few products use a refresh rate sufficiently high enough to ensure users do not experience motion sickness. In AR, Google Glass used a prism, but this is a transitionary technology and a transparent display will ultimately be adopted so that AR CG can be displayed on a wider field of view.

We think that if it becomes possible to manufacture high-performance transparent displays at low cost, the VR/AR headset market will take off rapidly. We would see a figure of around $20 as one benchmark, enabling cheaper headsets and extending battery life.

Figure 47. Size and Price of Small Displays and VR/AR Displays




Source: Display Search, Citi Research

## Battery for VR/AR

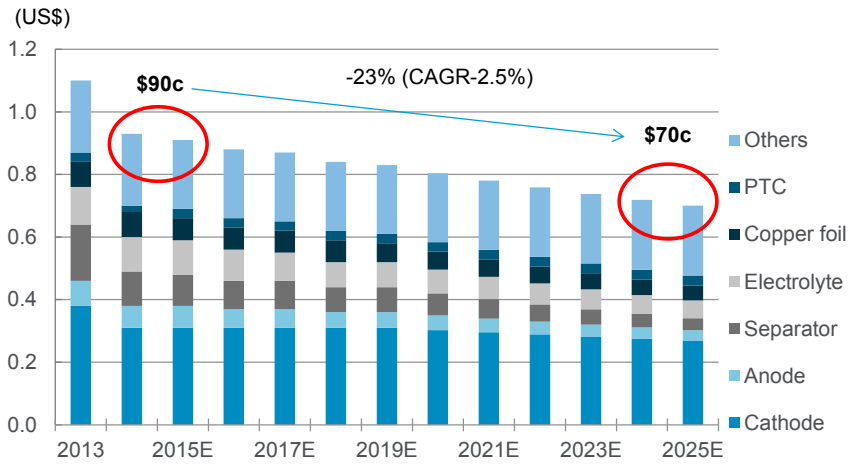
Energy density of batteries is an issue

A rechargeable battery will be necessary for headsets. A power supply from a battery that can ensure mobility will be particularly important for AR, as it is intended for use when the user is out and about and moving around. A battery that is sufficiently compact and of a high enough capacity to eliminate the need for a connecting cable and extend usage times will drive more rapid market growth. We think it would be sufficient for the battery to last long enough to watch a two-hour rugby match using VR and spend three hours of instrument panel operations via AR.

An AR headset would not necessarily use more power than a current smartphone. The display size would not be as large as 5", and the amount of power used for backlighting (or self-lighting in the case of OLED) would be smaller. However, the batteries would need to be smaller and lighter than those used in handheld smartphone in order for it to be integrated into a device worn on the head. Ultimately, we assume that power consumption would be about the same as for a smartphone, and that market uptake of high-performance AR headsets would be greatly aided by a reduction in the size of batteries to around one-quarter thanks to advances in energy density.

This may not seem that big a change relative to performance improvements for other electronic components. However, this is because battery performance is determined by the underlying principles of chemical reaction. Chemical reactions are not impacted by efforts to increase efficiency or by spending more money. Therefore, we think improvement in battery performance will be relatively slow. One potential workaround is using wireless charging, or promoting the uptake of replacement batteries.

**Figure 48. Lithium-Ion Battery Cost Reductions Slower than Those for Other Components**




Note: We use the expected cost trend for an 18650 cylindrical 2.2Ah battery.
Source: TSR, Citi Research

## Connector/Sensor Companies Benefit from Sensory Information Demand in Virtual Reality/Augmented Reality Applications

**Jim Suva, CPA**
U.S. IT Hardware & Tech Supply Chain Analyst

We believe the connector and sensor industry will benefit from the VR/AR end demand growth. In fact, we have seen increasing VR/AR applications in Gaming (i.e. Microsoft HoloLens), Auto (i.e. BMW Head-Up Display Technology), Industrial (harsh environment simulation) and Military/Aerospace. We use Google Glass content value as a proxy for connector sensor content dollar amount per VR/AR device to estimate the total addressable market (TAM) for the connector and sensor industry. Our TAM analysis indicates VR/AR application can contribute 2% and 4% incremental demand to connector and sensor total market respectively. We note incremental demand for sensors is higher than connector demand, as VR/AR devices have intense sensory information demand to track and react to the user's actions.

Connectors in VR/AR devices are mainly embedded in printed circuit boards. We estimate that the connector content dollar amount in Google Glass is ~$1.00-$1.50 or 0.8% of the total device value, roughly in line with dollar content in a smartphone. While military and medical VR/AR should require higher quality connectors with higher average selling prices, we believe connector dollar content as percent of total device value is at a 0.5-1.0% range across all VR/AR devices.

Thermal and Optic are two major sensory applications in VR/AR devices. Sensors are normally built in liquid crystal on silicon (LCOS) modules and camera modules. We estimate the sensor content dollar amount in Google glass is ~$5 or 3-4% of total device value. We believe the sensor component could reach a higher portion of total device value in certain industrial and military VR/AR applications such as harsh environment simulation and field force data visualization, which require high-quality sensing information for mission critical applications.

With our TAM analysis, we believe Amphenol, TE Connectivity, and Sensata will all benefit from the increasing use of VR/AR devices. TE Connectivity ranks as the leading connector company in the consumer device end market and the company recently acquired Measurement Specialty, a sensor company with technology in wearable devices. Similarly, Amphenol has had a long tradition in the Apple supply chain and we believe the company is a connector supplier to Apple Watch. We also believe Sensata could benefit from AR application in the industrial segment, as the company has 33% exposure in heavy vehicle and industrial sensing applications as well as a strong position in industrial automation.

**Figure 49. Connector and Sensors in VR/AR Analysis**

| | Connector | Sensor | Total Device Value |
|---|---|---|---|
| Google Glass | $1.0-$1.5 | ~$6 | $152 |
| Note | PCB component with embedded connectors | Liquid Crystal on Silicon (LCOS) Panel with embedded thermal sensor and camera module with embedded optical sensor | |
| Value of embedded module | $4.1 | $25.0 | |
| Content as % of embedded module | 30% | 20% | |
| Content % of total device value | 0.8% | 3.3% | |
| Total VR/AR TAM ($bn) | $0.82 | $3.29 | $100bn |
| Total Industry Market Value ($bn) | $65 | $80 | |
| Incremental contribution | 2% | 4% | |

Note: 1) Connector industry market value as of 2014 according to Bishop; 2) Sensor industry market value as of 2015 according to Sensata company presentation.
Source: Citi Research

# Software, Platform Creation, and Infrastructure

## Venture Companies and Mid-Sized Firms Making Significant Contributions to VR Software

Ventures and large-cap

The VR/AR industry is basically divided between venture/start-up companies and large-cap IT companies. There are many examples of venture company acquisitions by large corporates. In the last three years, Facebook acquired Oculus for $2 billion, Alibaba and others invested $790 billion in Magic Leap, Softbank and others invested $80 million in NextVR, and Disney invested $650 billion in Jaunt.

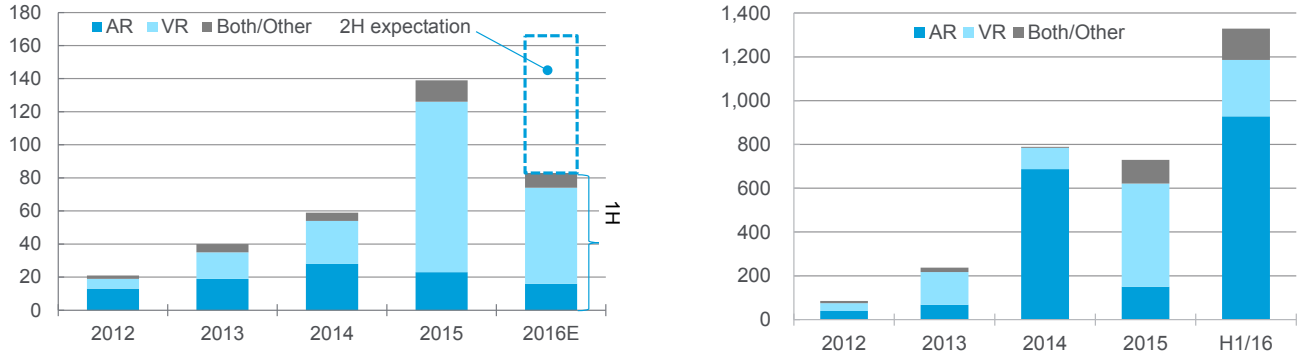
The number of merger and acquisition (M&A) deals has increased sharply in 2016. We believe the release of VR headsets and the emergence of experimental headset and service platforms are raising awareness of VR as a business domain, and that this forms the backdrop to robust M&A activity. We expect AR to follow a similar trend.

M&A continues at a rapid pace

M&A amounts are on a relentless upward trajectory. VR via smartphones is comparatively straightforward and approachable, so expectations are mounting that it will spread fairly quickly, and we see this as the trigger for the M&A boom. A series of specialized smartphone headset releases is contributing to the improvement of industrywide monetization.

Moving forward, we expect authoring and plug-in startups to get caught up in the M&A fray. We believe industry participants will increasingly recognize the importance of M&A deals for resources related to live streaming, processing software for platforms that support multiple VR users simultaneously, and communication protocols, and that this will further stimulate M&A.

**Figure 50. Cumulative Timeline for Major M&A Deals by Number (left) and Value (right, US$, millions)**




Source: CB Insights, Citi Research

Who are the software ventures?

VR/AR software includes engines and apps installed on the infrastructure side, and content creation software. The development and commercialization of such software is advancing in a closely integrated fashion.

Many companies are developing VR software. Authoring software and plug-ins developed by Unity, Mindlight, Finwe, Kadinche, and other startups are gaining market traction. The products are used to process content into a VR format that can be replayed on Android, iOS, and Windows platforms.

AR software development is also advancing. Microsoft and Google are proceeding with development by acquiring the assets of startup companies, and at this time they appear to have a lead over other developers.

## In AR, Content and Platform Generally Closely Connected

**Walter H Pritchard, CFA**
U.S. Software Analyst

**Kenneth Wong, CFA**
U.S. Vertical Application Software, Emerging Hardware Analyst

AR engines are being developed by large companies like Microsoft and Google. AR development for the Microsoft HoloLens is enabled through Windows Holographic, a development tool built into Visual Studio that doesn't require a separate software development kit (SDK). This move maintains the hardware-agnostic goal of Windows 10. Google brands its AR engine as Tango, which allows users to experience AR through their cell phones. Development for Tango is enabled through the Tango Java application program interface (API) which runs on Android Studio. We note that both Microsoft and Google AR engines rely on the Unity SDK, which is a required download in order to develop for Windows Holographic and Tango. Hardware costs for each AR offering from Microsoft and Google significantly vary. Microsoft currently charges $3,000 for the development edition of its HoloLens, while Google is currently working with phone vendors to integrate Tango hardware into handsets. The Phab2 Pro, the first consumer device with Tango integration, was released by Lenovo earlier this year and costs $500.

## Are the Networks Ready?

**Michael Rollins. CFA**
N. America Telecoms & Communication Infrastructure Analyst

Entertainment, gaming, and other sectors are preparing to deliver content in VR and AR, but are the networks of the world ready to deliver it to customers?

### Passing the First Test – Pokémon Go

We've had the first real test with Pokémon Go, an AR game where players attempt to capture characters that are superimposed on a map of their location. Since the characters' images are low quality, and the data being downloaded is maps that may already be in the phone's cache, surveys have shown limited data usage requirements. As we wrote recently in Mobile Users Search for Pokémon, Carriers Look for Usage, our study of Internet reviews of the service suggest the average customer uses about 10-20 MB per hour and most is originated on the mobile network. This is a limited amount of data compared to streaming video applications.

**Figure 51. Pokémon Go Data Usage Per Month Estimate vs. Streaming Video (HD and SD)**

| | SD-Video | HD-Video |
|---|---|---|
| Mbps | 2. 0 | 4.4 |
| / bits per byte | 8 | 8 |
| x seconds per minute | 60 | 60 |
| **= MB per minute** | **15** | **33** |
| x minutes per hour | 60 | 60 |
| **= MB per hour** | **900** | **1,980** |
| | | |
| | | |
| Pokémon Go Usage per hour MB (est.) | 15 | 15 |
| / Video MB per hour | 900 | 1,980 |
| **= Pokémon Go % of Video Usage** | **1. 7%** | **0 .8%** |

Source: Citi Research, CNET.com, Mobipicker.com, AndroidCentral.com

### Waiting for the Real Test – Virtual Reality

AR is an easier test to pass than VR; the underlying data requirements are generally handled be existing networks (i.e., Google Street Images) and the overlaid data is of a limited size currently. Virtual reality is far more complex because it is simultaneously transmitting multiple images and with greater frames per second than 'regular' video. It's a topic first explored by Jason Bazinet in his note Crossing the Rubicon: Navigating the Transition: Linear Video to Usage Based Pricing, where the increasing quality of streaming video was compared to data caps.

What are some of the challenges of creating VR?

Extending his analysis of required bandwidth to deliver a video stream, we can see that the current generation of VR headsets could require more data than a 4K video delivered by a streaming service. VR video requires two simultaneous video streams, one for each eye, and current generation headsets can show HD streams. The second key variable for bandwidth is refresh rate, or frames per second; VR headsets allow users to have a 100-110 degree field of view that shifts as they turn their head, requiring a likely higher refresh rate. We have assumed the maximum refresh rate for each device.

As shown in Figure 52, the bandwidth requirements of current generation VR headsets is greater than that of 4K video streams coming from pay TV and streaming video providers. While the resolution (pixels per frame) is lower, we'd expect the refresh rate to be far higher than that of traditional video given the need for smooth transitions as the user's perspective in the virtual world changes. Should the refresh rate be similar to the traditional 24 frames per second, bandwidth requirements would fall to 6-8 Mbps for existing VR headsets.

**Figure 52. Current Generation Virtual Reality Players Require More Bandwidth than a 4K Video Stream**

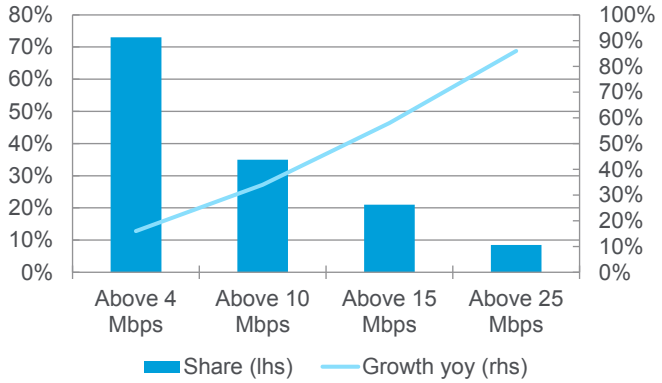
| | SD | HD | Full HD | Quad HD | 4K | 8K | Samsung Gear VR | Oculus Rift | HTC Vive | PlayStation VR |
|---|---|---|---|---|---|---|---|---|---|---|
| Pixels per frame (horizontal) | 720 | 1,280 | 1,920 | 3,840 | 4,096 | 7,680 | 2,560 | 2,160 | 2,160 | 2,160 |
| x Pixels per frame (vertical) | 480 | 720 | 1,080 | 2,160 | 2,160 | 4,320 | 1,440 | 1,200 | 1,200 | 1,200 |
| = Total pixels per frame (mil) | 0.3 | 0.9 | 2.1 | 8.3 | 8.8 | 33.2 | 3.7 | 2.6 | 2.6 | 2.6 |
| x Bits per pixel | 8 | 8 | 8 | 8 | 8 | 8 | 8 | 8 | 8 | 8 |
| = Total bits (mil) | 2.8 | 7.4 | 16.6 | 66.4 | 70.8 | 265.4 | 29.5 | 20.7 | 20.7 | 20.7 |
| x Colors (red, blue, green) | 3 | 3 | 3 | 3 | 3 | 3 | 3 | 3 | 3 | 3 |
| = Total Bits per frame (mil) | 8.3 | 22.1 | 49.8 | 199.1 | 212.3 | 796.3 | 88.5 | 62.2 | 62.2 | 62.2 |
| x Frames per second | 24 | 24 | 24 | 24 | 24 | 24 | 60 | 90 | 90 | 120 |
| = Bit rate (Gbps) | 0.2 | 0.5 | 1.2 | 4.8 | 5.1 | 19.1 | 5.3 | 5.6 | 5.6 | 7.5 |
| / Bits per byte | 8 | 8 | 8 | 8 | 8 | 8 | 8 | 8 | 8 | 8 |
| = GB per second | 0.0 | 0.1 | 0.1 | 0.6 | 0.6 | 2.4 | 0.7 | 0.7 | 0.7 | 0.9 |
| x Seconds per minute | 60 | 60 | 60 | 60 | 60 | 60 | 60 | 60 | 60 | 60 |
| x Minutes per hour | 60 | 60 | 60 | 60 | 60 | 60 | 60 | 60 | 60 | 60 |
| = GB per hour (uncompressed) | 90 | 239 | 537 | 2,150 | 2,293 | 8,600 | 2,389 | 2,519 | 2,519 | 3,359 |
| x Compression (H.264 codec) | 0.004 | 0.004 | 0.004 | 0.004 | 0.004 | 0.004 | 0.004 | 0.004 | 0.004 | 0.004 |
| **= GB per hour** | **0.3** | **0.9** | **2.0** | **8.0** | **8.5** | **32.0** | **8.9** | **9.4** | **9.4** | **12.5** |
| memo: bandwidth (Mbps) | 0.7 | 2.0 | 4.4 | 17.8 | 19.0 | 71.1 | 19.8 | 20.8 | 20.8 | 27.8 |
| | | | | | | | | | | |
| = GB per hour (uncompressed) | 90 | 239 | 537 | 2,150 | 2,293 | 8,600 | 2,389 | 2,519 | 2,519 | 3,359 |
| x Compression (HEVC codec) | 0.002 | 0.002 | 0.002 | 0.002 | 0.002 | 0.002 | 0.002 | 0.002 | 0.002 | 0.002 |
| **= GB per hour** | **0.2** | **0.4** | **2.0** | **4.0** | **4.3** | **16.0** | **4.4** | **4.7** | **4.7** | **6.3** |
| memo: bandwidth (Mbps) | 0.4 | 1.0 | 2.2 | 8.9 | 9.5 | 35.6 | 9.9 | 10.4 | 10.4 | 13.9 |

Source: Citi Research

## Network Can't Handle the Speed

Can the networks handle such speed? We turn to the Akamai 'State of the Internet' report, which uses their global content delivery network (CDN) to estimate the speed of Internet connections by country and globally. The first quarter 2016 edition of their report shows that fewer than 10% of global connections are greater than 25Mbps, a level that is barely able to meet the demands of today's VR headsets. Looking at the country data, a sample of markets in developed and emerging markets shows there is a wide disparity in network connection speeds between regions.

**Figure 53. Global Share of Data Connections by Speed**




Source: Akamai Q1 2016 'State of the Internet 'Report

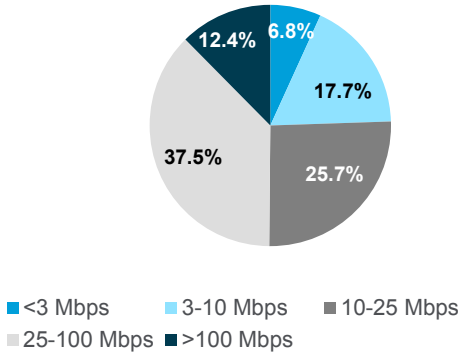
**Figure 54. Share of 'Above 15 Mbps' Connections by Region**

| Developed | Share | Emerging | Share |
|---|---|---|---|
| Japan | 44% | Russia | 24.00% |
| Belgium | 38% | South Africa | 7.70% |
| United Kingdom | 36% | Mexico | 4.00% |
| United States | 35% | India | 2.00% |
| Canada | 32% | Brazil | 1.10% |
| Germany | 26% | Vietnam | 0.80% |
| Israel | 24% | Nigeria | 0.50% |
| Australia | 10% | China | 0.40% |
| **Average** | **30.60%** | **Average** | **5.10%** |

Source: Akamai Q1 2016 State of the Internet Report

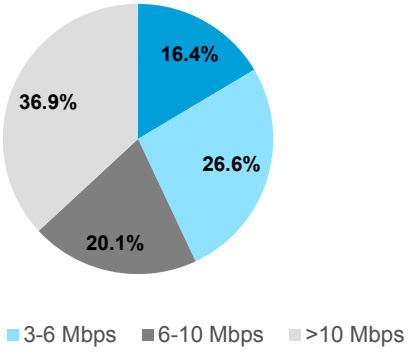
In the United States, the Federal Communications Commission (FCC) reports data based on actual carrier data, giving a real window into which broadband speeds residential users are currently subscribed. This is different from the Akamai data, which reports real bandwidth usage versus what a residential customer is subscribed to; differences may stem from network congestion in other parts of the network. According to the latest reported data, 50% of fixed broadband connections were for more than 25 Mbps on the downlink, with 12% capable of more than 100 Mbps. Approximately one-third of mobile connections have a minimum downlink speed of 10 Mbps or more, but this doesn't speak to real-time data.

**Figure 55. Fixed Connection Distribution by Downlink Speed**




Source: FCC Internet Access Services Report as of June 30, 2015

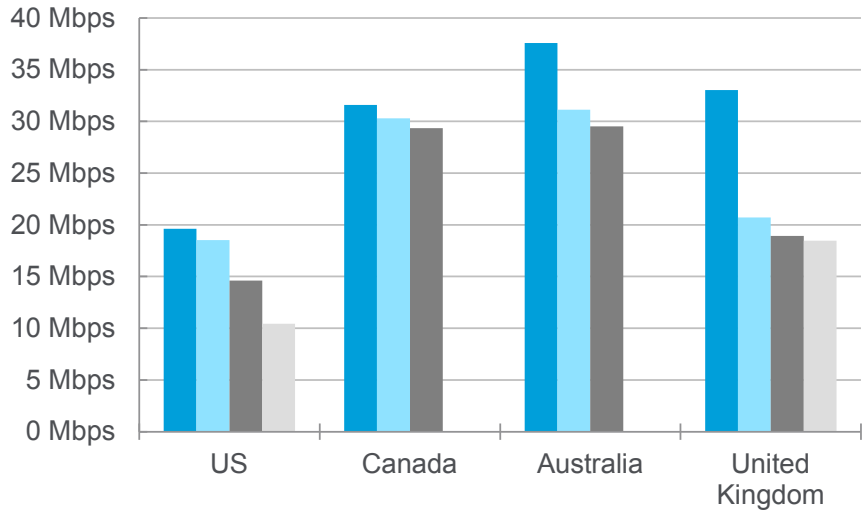
**Figure 56. Mobile Connection Distribution by Minimum Downlink Speed**




Source: FCC Internet Access Services Report as of June 30, 2015

Ookla, an on-line speed measurement tool, gives awards for the fastest mobile Internet service provider (ISP) by country based on customers who use their speed test tool. In the last test in 2015, we can see that average speeds in four developed market countries ranged from 10-38 Mbps depending on the carrier. We think this shows that mobile connections will largely struggle to handle streaming virtual reality video.

**Figure 57. Average Mobile Downlink Speeds by Carrier by Country**




Source: Speedtest.net/awards, retrieved August 24, 2016

# VR/AR Content & Services

## Biggest Markets: VR/AR Content and Services

Content and service markets larger than hardware markets

We think that headsets and other hardware will account for most VR/AR market value over the next five years or so, but that economic activity utilizing this hardware will expand steadily and subsequently form the core of the market. By 2020, we would expect the software and services market to have overtaken the hardware market. The hardware market will face a trade-off between the ongoing decline unit prices for hardware and market uptake, so growth in the value of the market is likely to slow. However, as the infrastructure base of installed hardware expands, the content and services market is likely to grow rapidly over the medium to long term. In this section, we look at the VR/AR content and service industry, and the outlook for future growth.

Market even larger when commerce using VR/AR is added in

As well as content and services, we expect the e-commerce industry to be greatly impacted by VR/AR. This outlook should provide powerful support to the cost of introducing VR/AR, and we see it as highly important. Currently, the world e-commerce and mobile commerce market is around $1 trillion, but we forecast growth to $4 trillion in 2030. Even if it starts with only several percent of the market, if VR/AR is applied to e-commerce, its growth should be a powerful driver of the expansion in the VR/AR market overall. Compared with the markets for hardware and for content and services, the e-commerce market is huge in value terms and directly connected to consumers' lives.

**Figure 58. Content and Services Introduced in This Report**

| Category in Contents & Service | Specific Focus |
|---|---|
| Console & Mobile game | PlayStation VR, Pokemon Go, Arcade Game |
| Amusement (Theme park) | VR Coaster |
| Media | News, Movie |
| Sports, Music | NBA, DeNA/SoftBank, F-1, LiveNation |
| Marketing | Travel agency, Real estate, marketing by Jaguar Land Rover/Volkswagen |
| Automotive | AR as evolution of human machine interface (HMI) |
| Medical & Healthcare | Diagnostic, Simulation, Training |
| Industrial use, Factory operation | Work and operational support |
| Office use | Conference, trading systems |
| VR/AR Commerce | Internet shopping |

Source: Citi Research

## Gaming

### Games to Supply Content to VR Market

**Rimi Yoshida**
Japan Game Analyst

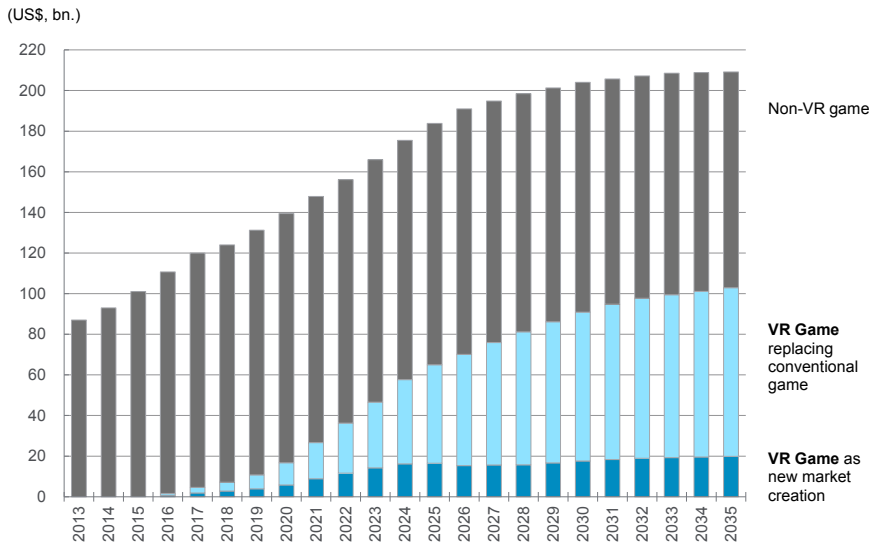
Irrespective of the type of hardware (consoles, in which we include PC games, mobile or arcade) or the genre (role playing, shooting, action, puzzle), gaming is a type of leisure activity that involves the player performing a particular role in a virtual world in order to achieve an objective. It is highly compatible with virtual reality, and we think it will be one of the main types of content in the VR market.

We project VR game market of $49.4bn in 2025 (total for consoles, mobile, arcade)

We estimate the global game content market was $101 billion in 2015 (total for console, mobile and arcade games). The breakdown by type of hardware was $55.8 billion for console games, $21.0 billion for mobile games, $8.3 billion for arcade games and $3.9 billion for others. We forecast growth in the market to be driven partly by the strong tailwind provided by VR games to around $132 billion in 2020 and $162 billion in 2025. Our market CAGR forecasts are 4.8% for 2015–2025 and 1.6% for 2025–2035.

For VR games alone, we forecast the market at $10.7 billion in 2020 and $49.4 billion in 2025. By type of hardware, we think console games will be the biggest, but that there will be rapid growth also in mobile and arcade game VR titles.

**Figure 59. Global Gaming Context Market Forecasts (Total for Consoles, Mobile and Arcades)**




Source: IDC, Gartner, VG Chartz, Citi Research

Hardware types: Differentiated markets for consoles, arcades, mobile

From the perspective of hardware properties, we think content density will mean that arcade games, which use hardware designed specifically for the individual title, will provide the richest experience, followed by console games, which have a large content capacity, and then mobile games. However, from the perspective of ease of access to content, the order will be reversed, with mobile games first, followed by console games and then arcade games. At this point, we think there will be differentiated markets for VR games for each type of hardware.

**Figure 60. Accessibility and Richness Matrix for VR Games (Arcade, Console, Mobile)**

| | Arcade Games | Console Games | Mobile Games |
|---|---|---|---|
| Convenience (ease of access) | △ | ○ | ◎ |
| Richness of content | ◎ | ○ | △ |

Source: Citi Research

Genres: RPGs, action games the VR game pioneers

By genre, we think that role-playing games (RPGs) and action games are more compatible with VR, given the sense of reality possible using 3D graphics, than puzzle games, which are better suited to 2D and flat surfaces. We also expect shooting games, racing games, and sports games to become compatible with VR, but these genres have particularly demanding requirements in terms of seamless graphic motion and rapid screen manipulation and response times, so it will be more difficult than for RPGs to prevent VR sickness, which we discuss below.

"Sense of presence" the big difference between VR games and non-VR games

While we expect strong market growth, VR games have very different properties to non-VR games, so game companies will need to change their development philosophies.

In most non-VR games other than first-person shooting (FPS) games, the player observes the action through a camera that is slightly behind the main character, so the field of vision is more like that of a third-person shooting (TPS) game. In VR games, however, the player's field of vision will be exactly the same as that of the main character, so it will be more like a FPS game, making it easier to give the player the sense of immediacy and immersion of "actually being in that world," or in other words, a sense of presence. From the perspective of the thrill experience by the player, the player experiences the excitement by transferring her emotions to the traditional third-party main character in a non-VR game. But in a VR game, the player herself can experience adventures as she is one and the same as the main character. This means that if the quality of the story and character graphics is sufficiently high, a player can experience the excitement of a non-VR game by transferring his emotions to the main character. VR games, however, rely on an approach based on the player's own five senses, and must directly engage the senses of sight and sound, which play the biggest roles.

**Figure 61. Characteristics of VR and Non-VR Games**

| | Player Perspective | Source of Enjoyment | Motion Sickness |
|---|---|---|---|
| VR games | First person | Player's own experience | Common |
| Non-VR games | Mainly third person | Connection with characters in game | Uncommon |

Source: Citi Research

Irrespective of the type of hardware or genre, in the current early stages of VR, game companies are already developing VR games in a broad range of genres, as shown by Figure 62.

**Figure 62. Major VR game titles**

| Category | Title | Company Name | Overview | Release Date |
|---|---|---|---|---|
| **PS VR** | JOYSOUND VR | XING Inc. | Karaoke | 10/13/2016 |
| | Rez Infinite | Enhance Games | Shooting | 10/13/2016 |
| | Biohazard 7 Resident Evil | CAPCOM Co., Ltd. | Survival Horror | 1/26/2017 |
| | VR Tennis Online | COLOPL, Inc. | Sports | 2016 Winter |
| | Fly to KUMA | COLOPL, Inc. | Puzzle | 2016 Winter |
| | Heading Factory ( Probably) | GEMDROPS Game studios | Heading action | 10/13/2016 |
| | Final Fantasy XV | SQUARE ENIX Co., Ltd. | RPG | 11/29/2016 |
| | Cyber Danganropa VR Class Trial | Spike Chunsoft Co., Ltd. | Reasoning action | 10/13/2016 |
| | Miku Hatsune -Project DIVA- X HD | SEGA Games Co., Ltd. | Rhythm action | 8/25/2016 |
| | Miku Hatsune VR future live | SEGA Games Co., Ltd. | Live concert | 10/13/2016 |
| | Happy Manager | D3 PUBLISHER Inc. | Love ADV | 2016 Winter |
| | Summer lesson (Probably) | BANDAI NAMCO Entertainment Inc. | Character communication | 10/13/2016 |
| | Idolmaster Cinderella Girls viewing Revolution | BANDAI NAMCO Entertainment Inc. | Idol Live | 10/13/2016 |
| | Tekken 7 | BANDAI NAMCO Entertainment Inc. | Action | Undecided |
| | Ace Combat | BANDAI NAMCO Entertainment Inc. | Flight action | Undecided |
| | Roller coaster Dreams | Bimboosoft | Simulation | 10/13/2016 |
| | Eagle Flight | Ubisoft Entertainment S.A. | Flight action | 10/13/2016 |
| | Sleepless Souls | wise | Interactive Cinema | 10/13/2016 |
| | Batman: Arkham VR | Warners Bros. Japan LLC | Action | 10/13/2016 |
| | THE PLAYROOM VR | Sony Interactive Entertainment Inc. | Party | 10/13/2016 |
| | PlayStation VR WORLDS | Sony Interactive Entertainment Inc. | Variety | 10/13/2016 |
| | RIGS Machine Combat League | Sony Interactive Entertainment Inc. | FPS Sports | 10/13/2016 |
| | Until Dawn: Rush of Blood | Sony Interactive Entertainment Inc. | Horror shooting | 10/13/2016 |
| | Tsumiki BLOQ VR | Sony Interactive Entertainment Inc. | Puzzle | Nov-16 |
| | Gran Turismo Sport | Sony Interactive Entertainment Inc. | Driving simulator | 11/15/2016 |
| | Days Gone | SIE WWS Bend Studio | Action | Undecided |
| | Spider-man | Insomniac Games | Action | Undecided |
| | LEGO Star Wars: The Force Awakens | TT Games and Warner Bros. | Action adventure | 10/13/2016 |
| | God of War | SIE WWS - Santa Monica Studio | Action | Undecided |
| | DEATH STRANDING | Kojima Productions | Action | Undecided |
| **Oculus Rift** | AirMech: Command | CARBON | Strategy | Mar-16 |
| | Chronos | Gunfire Games | Action | 3/28/2016 |
| | Rooms | Steam | Puzzle | Mar-16 |
| | Shufflepuck Cantina Deluxe VR | Agharta Studio | Sports | 3/28/2016 |
| | Pinball FX2 VR | Steam | Pinball | Mar-16 |
| | Farlands | Oculus | Adventure | 3/28/2016 |
| | Oculus Dreamdeck | Oculus | Entertainment | 3/28/2016 |
| | Damaged Core | High Voltage Software, Inc | Action shooting | 8/30/2016 |
| | Esper: The Collection | Coatsink | Puzzle | 3/28/2016 |
| | EVE:Valkyrie | CCP Games | Action shooting | 3/28/2016 |
| **Gear VR** | Baskhead | VR-lines | Action sports | 7/22/2016 |
| | Adventure Time: Magic Man's Head Games | Steam | 3D action | Undecided |
| | Audio Arena | Skydome Studios | Rhythm shooting | 11/25/2015 |
| | Darknet | E McNeill | Encampment game | 4/19/2015 |
| | Hypercade | Hidden Path Entertainment | Action | 8/31/2016 |
| | Gun Club 3 VR | The Binary Mill | Action shooting | 6/29/2016 |
| | Espe | Coatsink | Puzzle | 4/18/2015 |
| | Wrath of Loki | The House of Fables | Adventure puzzle | 8/31/2016 |
| | Mr Cat's Adventure | FiresVR | Adventure puzzle | 8/31/2016 |
| | Land's End | usutwo games | Adventure | 11/20/2015 |
| | Deer Hunter VR | Glu Games Inc | Shooting sports | 12/3/2015 |
| | Into the Dead | PikPok | Action adventure | 11/25/2015 |

Source: Citi Research

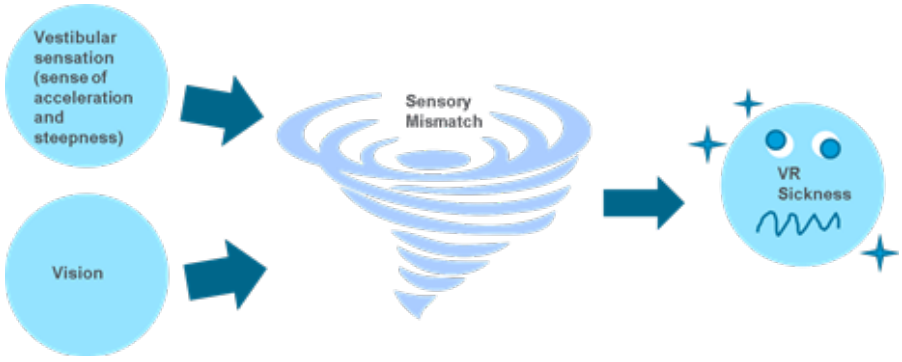
## Experiences Unique to VR (1): Balance Between sense of presence and VR sickness

Sense of presence (immediacy, immersion) required of VR vs. VR sickness

Acting mainly on the sense of sight via graphics, VR games in general require a 360-degree field of view, so developing the graphics is more complex than for non-VR games. In addition, the user interface that displays status (such as hit point gauges and item boxes on the screen) in non-VR games would not normally be visible to the main character (i.e., the player) in the game space, so they are likely to degrade the sense of presence for a VR game. It will therefore be necessary to achieve both the provision of the information necessary to play a game as well as the sense of presence.

Innovations to prevent VR sickness are also an important issue. VR sickness occurs when the visual information in the VR space displayed on the head mounted display does not match the vestibular sensation provided by the player's own body. The sickness caused by the resulting illusion of self-motion, known as vection, can have symptoms such as nausea, headaches and sleepiness. VR sickness is a critical issue that must be overcome by VR game developers, and game companies are each coming up with their own innovations.

**Figure 63. How VR sickness occurs**




Source: Citi Research

Capcom's Biohazard 7 is the first big title completely VR compatible

Biohazard 7: Resident Evil, due for release by Capcom for the PS4 and Xbox One in January 2017, will likely be the first example of a title that achieves both the sense of presence and VR sickness prevention.

This is a full number title in the Biohazard series that has racked up cumulative global sales of just under 70 million copies. The recent full number titles have been Biohazard 5, released in May 2009 for the PS3 and Xbox 360, which sold around 7 million copies, and Biohazard 6, release in October 2012 for the PS3 and Xbox 360, which sold around 6.6 million copies. The new Biohazard 7 returns to the origin of the series in survival horror, and will apparently appeal to the player's sense of fear. It will be the first big Capcom title fully compatible with VR (the entire game has VR mode). The appeal of the horror game genre is the sense of immersion and immediacy experienced by the player and the fear that this causes, so the genre is well suited to VR games, given the sense of presence. In this sense, Biohazard 7 will be a focus as a driver of VR market growth.

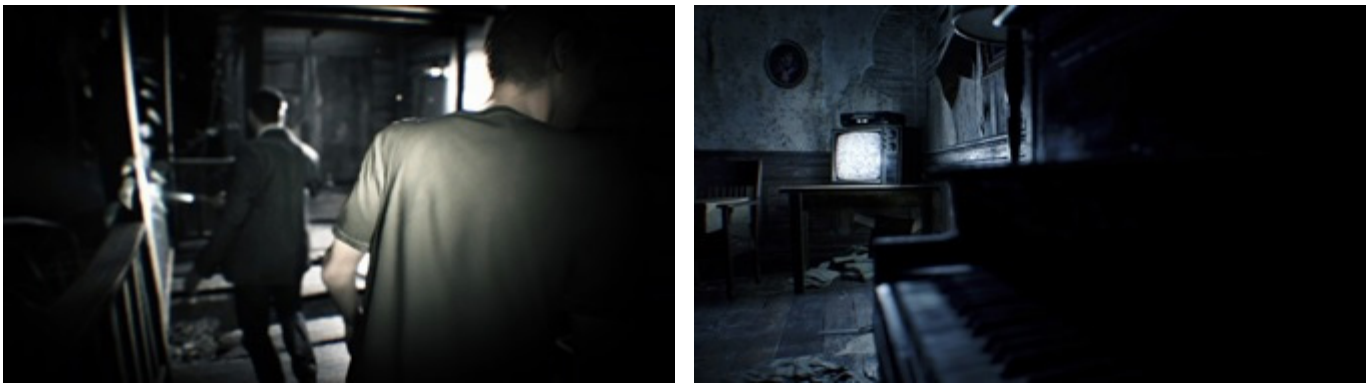
As much as possible, the title does away with the type of user interface considered only natural in non-VR games, such as the hit point gauge and other status displays and item box displays, in order to maximize the sense of presence. For example, detailed information on an item discovered by a player is not displayed like a sticker on the screen, but rather appears in 3D in the VR space.

Innovations to prevent VR sickness in Biohazard 7

To avoid VR sickness, the title makes big changes to game play parameters such as camera operation and player movement speed between non-VR mode and VR mode. In non-VR mode, the camera can be operated smoothly and seamlessly throughout the entire field of vision, and it incorporates camera wobble when the main character moves (the wobbling is seen in the user's point of view due to the movement of the main character's body). Viewed from a non-VR TPS perspective, this type of camera operation gives a sense of immersion and immediacy similar to the sense of reality sought by documentary movie makers.

In a VR space, however, seamless camera operation and camera wobble would cause VR sickness, due to the mismatch between visual information and the vestibular sensation. So when Biohazard 7 is played in VR mode, the camera moves around 30 degrees when the player moves it left or right using the controller, and the point of view changes almost instantly. Because of this design, seamless camera operation is not possible. In addition, there is no camera wobble irrespective of whether the camera is fixed or moving, and the speed at which a player can move is reduced from around 6.1km/h in non-VR mode to about 4.2km/h in VR mode.

**Figure 64. Biohazard 7 (demo) Screenshots**



Source: Capcom, Citi Research


Capcom is always actively researching new hardware, new accessories and new technologies, and with Biohazard 7 it will beat the big third-party game companies to release a fully VR-compatible title. It is not known how much the effect of VR sickness on players will be reduced by the camera operation limitations imposed by the title in VR mode (non-seamless viewpoint movement, elimination of camera wobble when moving), but it will produce the first trial-and-error results. As Capcom and other game companies develop VR titles other than Biohazard 7, the knowledge they accumulate regarding VR sickness will enable them to develop titles with a greater degree of freedom.

## Experience Possible Only via VR: Stereophonic Sound without Background Music

Sound for Bandai Namco's VR ZONE Project i Can a progressive example

Like sight, hearing also plays a big role in achieving the sense of presence for VR games. The background music in non-VR games would normally not be audible to a player actually in a VR game space, so it could easily degrade the sense of presence. So in VR games there is likely to be an emphasis on environmental sounds such as the wind, rain, and insects instead of background music.

From the perspective of hearing, Bandai Namco leads the industry by leveraging the experience gained with its Mobile Suit Gandam: Ties of the Battlefield to incorporate new innovations into its VR ZONE Project i Can amusement arcade. VR ZONE Project i Can is an amusement arcade opened in Odaiba,in Tokyo, on April 15, 2016, and its eight VR-compatible arcade games are proving highly popular. The audio approach is well suited to VR, using natural sounds such as the wind and blowing snow, as well as the sound of skis in Ski Rodeo, and frightening stereo sounds such as dripping water and creaking metal in Escape Ward Omega, to create a sense of presence. The stereo technology that enables sounds to be heard from the front or back, left or right, and top or bottom as a player moves around is likely to play a particularly large role in creating a sense of presence in VR games.

One reason that Bandai Namco was able to open a VR amusement arcade before other big game companies is the experience it gained in VR games via the operation of its conventional arcade game Mobile Suit Gandam: Ties of the Battlefield.

What is Mobile Suit Gundam: Ties of the Battlefield?

Mobile Suit Gandam: Ties of the Battlefield is an arcade game based on the animated series Mobile Suit Gandam. It has a hemispheric screen called a panoramic optical display (POD), and the player sits in a big machine with a cockpit-type seat, enabling an experience close to actually controlling a big fighting robot. It has garnered deep rooted popularity since its launch as an arcade game in 2006.

It does not use a VR headset, and the images seen by the left and right eyes are the same, so the vision is not 3D but rather flat. However, as the user is surrounded by the POD, the visual experience is almost 360 degree. By projecting the game display via a projector onto a screen that envelopes the player's field of view, an experience similar to actually controlling a large fighting robot is possible.

The POD has full HD resolution (1920 x 1980 dots), which is around 2.6 times that of older projectors (XGA). The luminescence has been increased to make the screen brighter, and it is clear down to fine details. The player experiences the range of information on the display in great detail and realism, and we think this is behind the game's popularity.

However, it can be tiring to watch a screen in an enclosed space for long periods. The graphics on the display move rapidly, but the seat is fixed so it does not move, and some people feel sick because their sense of balance is confused. We think that the quality of the experience would be greatly enhanced by a seat that moves. We think the know-how gained from developing Mobile Suit Gandam: Ties of the Battlefield has been leveraged in the VR ZONE Project i Can.

## Innovation in VR Games Needed to Achieve Different Type of "Fun" in Non-VR Games

VR games provide a sense of immediacy and immersion by working on the five human senses, particularly sight and hearing. However, the challenge of appealing to consumers who have not played the game will be one issue for market growth. The fun to be derived from non-VR games, which usually have a TPS perspective, results from the player transferring his emotions to the main characters, and consumers who have yet to play the game can be attracted simply by showing content details and graphic vision. This is evident from the large number of TV commercials that show game playing graphics, be it for console or mobile games.

However, the pleasure derived from VR games results from the sense of presence that the player has of actually feeling like a part of the game world, which can only be experienced by actually playing the game. It is difficult, therefore, to communicate this by showing the game graphics in a TV commercial. Attracting consumers who have not played the game will therefore require a different type of know-how for VR games than for non-VR games. For well-known titles such as Biohazard and Final Fantasy, consumers will be able to envisage some of the content whether it is VR-compatible or not, so this will not be a problem. However, innovation will be needed for totally new games. For totally new VR games, we think that promotion and marketing will need to rely on showing players' reactions rather than the gaming display.

## VR Game Business Model: Innovation Should Compensate for Cost Increase

Impact of VR games on game software companies' profitability

Development costs will be higher for VR games than for non-VR games. However, we think game companies can offset this with innovations that improve development efficiency and by raising prices for games that provide a richer experience.

As discussed above, Capcom made big changes to Biohazard 7 in VR mode compared with non-VR mode in areas such as camera operation and the speed of player movement, so making the game VR-compatible will have resulted in additional costs. However, the company developed its own game production environment, RE Engine, at the same time it was developing Biohazard 7. The automation of development (for example, the automated addition of the sound of clothing rustling as a character moves) and the sharing of the production environment with team members should boost efficiency. We expect Capcom to use RE Engine for game titles other than Biohazard 7 in the future and think the company will leverage the know-how it has accumulated in development efficiency across a range of titles, thereby offsetting the additional costs of VR compatibility.

For arcade games that have hardware tailored to the title, there will be additional costs for the hardware required to achieve the sense of presence in addition to higher development costs. In Bandai Namco's VR ZONE Project i Can, the Ski Rodeo title enables players to ski on a slope in a VR space, and includes innovations such as the wind the a player feels while skiing, the vibration of steps, and the operation of the base (change in the slope as the player moves, etc.). In the Max Voltage title at VR ZONE Project i Can, the player becomes a singer performing live, and the hardware innovations that increase the sense of immediacy including sound proofing to prevent sound leading out and headphones with woofers. These are cost increases specific to VR-compatible arcade games. However, the cost of playing games at VR ZONE Project i Can is higher than other arcades, at ¥700–¥1,000. The price reflects the added value of playing VR-compatible games, but at this point the utilization rate of VR ZONE Project i Can is very high, so pricing appears to be acceptable to consumers.

Overall, we think that development innovations and pricing will mean that game companies can avoid a decline in profitability due to VR-compatible console games, mobile games and arcade games.

## VR 2.0: Evolution of VR Games

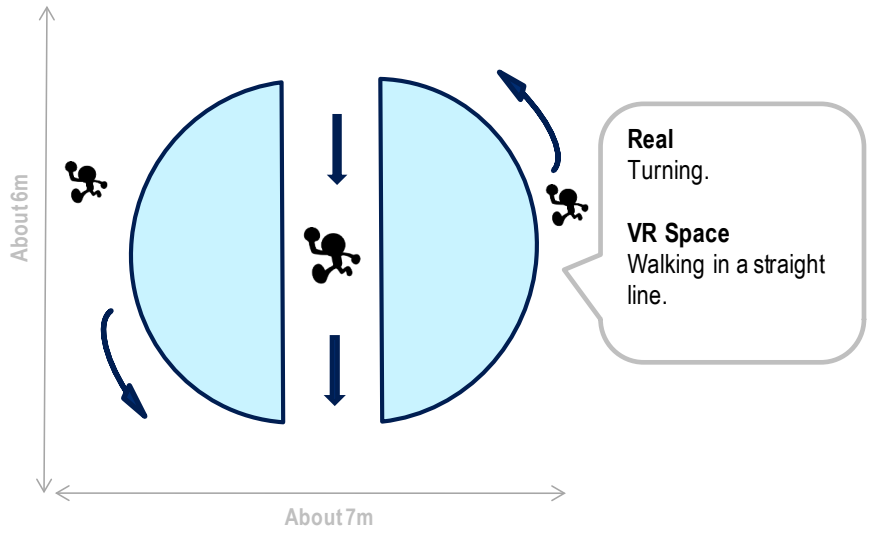
Touch and smell feedback, eye tracking, VR sickness prevention

To further improve the sense of presence, next generation VR games are likely to provide touch and smell feedback and use eye tracking technology. Academic research is progressing in this area, and we think it will be useful to improve the sense of presence for VR games within several years. Of the five senses, VR technologies are advanced for sight and hearing, but adding in other human senses will further increase the sense of immersion and immediacy.

To address the issue of VR sickness, we think that in addition to controlling sight information, it may also be worth trying innovations in the control of vestibular sensation information. Currently, there are two main innovations being trialed.

1. **Unlimited Corridor**: A player wearing VR googles slowly walks forward while touching a gently curving wall. If the wall shown in the VR googles is straight, the player feels as though she is walking straight even if the actual wall is curved. If the game is designed so that the player can continuously walk around the curved surface as shown in Figure 65, an "unlimited corridor" is created in the VR space. At the moment, this requires the construction of a curved wall that fits in a space of around 6m x 7m, so the content is designed for large spaces such as game arcades, but it is a good example of how a player's vestibular sensation can be matched to what she sees.

**Figure 65. Unlimited Corridor**




Source: Citi Research

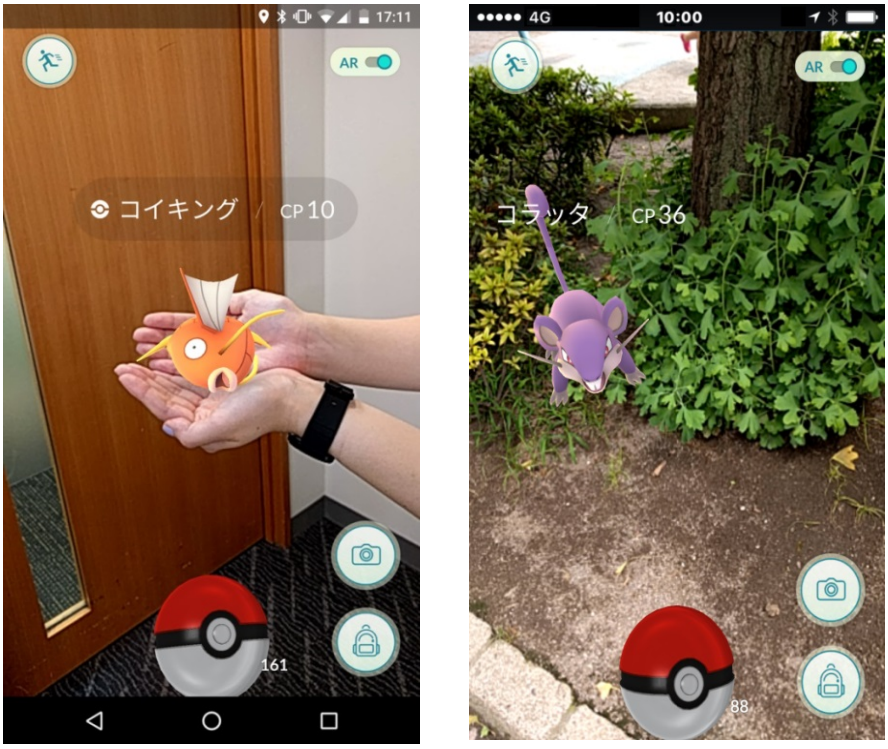
2. **Controlling Vestibular Sensation Using Electrical Stimulation**: This technology passes an electric current through electrode pads attached to the player's neck, giving the upright stationary player the sensation of moving up and down, left and right, and back and forwards. In current console VR games in which players are assumed to be stationary, rapid movement and turning in the VR space is considered almost taboo, as the mismatch between the vestibular sensation and vision causes VR sickness, but this technology enables the vestibular sensation to be matched to what is seen. It will take several years before it is commercialized for game titles, but it could lead to a break through that enables the broadening of console VR game content.

## AR Game: The Pokémon Phenomenon

Pokémon appear in the real world. The game differs considerably from the old format of manipulating the central characters in the game to find and look after Pokémon. The player becomes the central character in the real world, in which they search for Pokémon.

Pokémon Go is a smartphone app, and players move around the real world to catch, train and battle Pokémon. One characteristic is the game's use of AR technologies. Pokémon characters are superimposed on images of the real world captured by the smartphone's camera, making it appear that there are Pokémon in the real world.

**Figure 66. Characters Appear in the "Real" World**




Source: Niantic
©2016 Niantic, Inc.
©2016 Pokémon. ©1995-2016 Nintendo/Creatures Inc. /GAME FREAK inc.

The player uses a map on the phone that is based on Google Maps to move around the real urban environment and find Pokémon. When the player finds a Pokémon, the character appears in the image shown by the camera. The Pokémon can be captured by manipulating the smartphone to throw a ball at the character. When catching a Pokémon, the player gets the sense of immediacy characteristic of AR.

**Figure 67. Monsters Visible on a "Real World" Map Based on Google Maps**


Source: Niantic.


Development history and impact on business

The Pokémon Go Project started in April 2014. In September 2015 Pokémon Co. announced the project as part of a new business strategy. The project proceeded with the cooperation of Niantic, which was spun off by an internal Google start-up Game Freak and Nintendo, among others. It was released first in the U.S., Australia, and New Zealand in July 2016, before spreading to the rest of the world.

In August 2016, the number of downloads was recognized as a Guinness World Record in a number of categories. According to Guinness, there were 130 million downloads and sales reached $265 million in the first month. As Pokémon Go does not have great stickiness as a game, its popularity is likely to wane in the relatively short term, but it will be remembered as a hit game that combined popular characters with the AR concept.

Outlook

Currently, Pokémon appear to be in the real world if the player holds up their smartphone camera. We think that in the future players will be able to experience Pokémon Go with AR headsets such as Google Glass and Microsoft HoloLens. Mr. John Hanke, CEO of the developer Niantic, has also mentioned the use of headsets. Once market penetration of this type of technology increases, we are likely to see people in shopping malls and the like raising their hands to grasp massive gold coins that appear in the air (virtual coin CG).

Expectations for greater activity in AR games titles, location-based game titles

Before the release of Pokémon Go, the available AR games and location-based games included Colopl's Colony Life Plus (location-based game released in May 2003), Niantic's Ingress (location-based game released in December 2013), and Pixbox Studios' AR Free Flight (AR game released in May 2016). While Colony Life Plus was popular in Japan and Ingress was popular in the major markets that it was released in, neither was a worldwide hit like Pokémon Go. We expect increased activity in the development of AR and location-based games based on learnings from the explosive popularity of Pokémon Go.

Figure 68. Major AR games

| AR Game | | |
|---|---|---|
| **Game Title** | **Company Name** | **Release Date** |
| AR Free Flight | Pixbox Studios | Mar.2016 |
| **Pokémon Go** | **Niantic/Pokémon** | **Jul.2016** |
| Dragon Spotting | Disney | Aug.2016 (in the US) |
| Gold Castle | New York Lottery | Aug.2016 (in the US) |

Source: Citi Research

Figure 69. Major location-based games

| Location-based Game | | |
|---|---|---|
| **Game Title** | **Company Name** | **Release Date** |
| Colony Life | COLOPL, Inc. | May.2003 |
| Geocaching | Groundspeak Inc. | Oct.2008 |
| Zombies, Run! | Six to Start | Jun.2012 |
| Ingress | Niantic | Dec.2013 |
| **Pokémon Go** | **Niantic/Pokémon** | **Jul.2016** |

Source: Citi Research

# Amusement

## Amusement Park: Rollercoaster

VR coaster

A VR coaster involves riding a conventional roller coaster while wearing a wireless VR headset to enjoy CG vision. The rider feels the actual speed and G-forces of the roller coaster but is visually in a completely different world (scene). As the VR graphics are linked to the actual shape of the roller coaster, there is a sense of immersion that makes it feel like the rider is experiencing rapid descents, loops, and turns in a virtual space.

Rapid growth in VR coaster market in 2016

Theme parks such as Six Flags in the U.S. and Europa-Park in Germany have already installed VR coaster technology. We expect more than 20 theme parks to have installed VR coasters by end-2016.

## VR Coaster Providers

VR Coaster, a subsidiary of the German roller coaster builder Mac Rides, leads in VR coaster technologies. It was established in 2014 and has installed its proprietary technologies in more than 20 theme parks worldwide. It is therefore a pioneer in the VR coaster industry.

It has developed the VR video content that is key to the quality of the VR coaster experience as well as transmission systems, and has patented many technologies. As VR systems can be installed on existing roller coasters, we think that market penetration will increase quickly. The VR headsets used are the Samsung Gear VR, and Samsung Electronics was involved in some of the VR coaster development.

VR coaster structure

VR Coaster says that VR technologies can be installed on almost all existing roller coasters. The VR Coaster Box that contains the sensors is installed in the middle of the roller coaster. It transmits a signal that is coordinated with the violent movement of the roller coaster, and the riders' VR headsets show real-time 360-degree VR images.

Figure 70. A Single VR Coaster Box Can Sync Any Number of Headsets in Reach.

Source: VR Coaster

Figure 71. Introduction on the VR Coaster




Source: VR Coaster

Figure 72. Where Can You Ride the VR Coaster?

| Client Name | Country | Name of Roller Coaster |
|---|---|---|
| Six Flags Magic Mountain | USA | The New Revolution Virtual Reality Coaster |
| Six Flags Over Texas | USA | Shockwave Virtual Reality Coaster |
| Six Flags Over Georgia | USA | Dare Devil Dive Virtual Reality Coaster |
| Six Flags St. Louis | USA | Ninja Virtual Reality Coaster |
| La Ronde | Canada | Goliath Virtual Reality Coaster |
| Great Escape | USA | Steamin' Demon Virtual Reality Coaster |
| Six Flags New England | USA | Superman - The Ride Virtual Reality Coaster |
| Six Flags America | USA | Superman - Ride of Steel Virtual Reality Coaster |
| Six Flags Fiesta Texas | USA | Superman - Krypton Coaster Virtual Reality Coaster |
| Cedar Fair / Canada's Wonderland | Canada | Thunder Run VR Coaster |
| Cedar Fair / Cedar Point | USA | Iron Dragon VR Coaster |
| Europa-Park | Germany | Alpenexpress Coastiality |
| Europa-Park | Germany | Pegasus Coastiality |
| Bobbejaanland | Belgium | Mount Mara VR (aka Revolution) |
| Erlebnispark Schloss Thurn | Germany | Dinolino's VR Ride |
| Linnanmäki | Finland | Linnunrata eXtra |

Source: VR Coaster, Citi Research

**Figure 73. Six Flags Virtual Reality Coaster**


Source: VR Coaster

VR coaster market environment and outlook

VR coasters are attractive, as they can be added to existing infrastructure. There is a wide variety of content that enables users to experience a Jurassic forest, to fly around the sky, and to ride in a space craft. Consumers can therefore ride a VR coaster repeatedly without getting sick of it.

If a moving seat were developed, amusement facilities may be able to provide a similar experience to some extent with some sense of immediacy via acceleration without building major infrastructure such as an actual roller coaster. Samsung took its hardware to the Consumer Electronics Show in 2016 to provide users with such an experience.

**Figure 74. Samsung Gear VR in 2016 CES**


Source: Samsung Electronics

## Media, Hollywood, Movie Theaters, and Concerts

**Jason B Bazinet**
U.S. Entertainment, Media, Cable & Satellite Analyst

Just six months ago, we looked into Hollywood's investments in VR and AR. At the time, there were clear signs that the broader entertainment ecosystem was just beginning to make early stage investments. But, today, the level of investment - and the diversity of activity - has clearly increased. Not only are firms investing in early stage hardware firms, we're also seeing parallel investments in VR production firms. And, still other firms are beginning to layer in VR and AR capabilities into their existing businesses.

### Technology Investments

Jaunt, founded in 2013, is a virtual reality startup based in the U.S. The firm's technology provides an end-to-end solution for cinematic experiences in the VR format. To date, the firm has raised $100 million in capital, the largest capital raise so far for a VR startup. But what makes Jaunt interesting isn't the magnitude of the capital raise, per se. Rather, it's the firm's early ties to Hollywood.

**Figure 75. Jaunt 360 Degree Camera**


Source: Jaunt

Early investors include Disney (the lead investor), Evolution Media Partners (a partnership of CAA-backed Evolution Media Capital, TPG Growth and Participant Media), Google Ventures, Highland Capital, Redpoint Ventures, Sky, China Media Capital (CMC), ProSieben, Axel Springer, Madison Square Garden, and SV Angel.

However, Disney's relationship with Jaunt goes beyond early-stage financing. Indeed, ABC News Internet Ventures (owned by Disney) has used the startup's technology to produce about a dozen pieces of VR content including: the 2016 Republican National Convention, Inside Shanghai Disney, Inside Syria, GMA Concert Series, Busy Life of Bees, Chernobyl 30 Years Later, China's Own Eiffel Tower, Nepal: After the Earthquake, Inside North Korea, and NYC Holiday Cheer.

Disney isn't alone. A second media company, UK-based Sky, is also leveraging its investment in Jaunt to produce VR content. Gary Davey, the Managing Director of Content at Sky, recently announced a major commitment to VR. And, to accelerate development, the firm started Sky VR Studios, an in-house production unit. Early VR efforts focused on Formula One. And, over the next year, Sky plans to produce 20 films across several genres including major news and sporting events. Examples include heavyweight boxing, Tour de France, and a range of news, art and entertainment programming.

Jaunt isn't the only technology startup getting funding from Hollywood. NextVR has raised about $35 million from Formation 8, Comcast, Time Warner, Dick Clark Productions, MSG, Peter Gruber (co-owner of the Golden State Warriors and LA Dodgers) and RSE Ventures (a firm that specializes in entertainment investments). NextVR has streamed a few live events including a U.S. presidential debate and an NBA game.

## Production Investments

The commitment by media firms to VR isn't limited to early-stage technology firms like Jaunt and NextVR. We've seen production investments as well from firms like Comcast and Verizon.

Verizon, current owner of AOL, has used its Huffington Post subsidiary to acquire Ryot, a production firm specializing in VR content. Verizon plans to use Ryot to accelerate development of VR news coverage. Ryot executives have called VR an "empathy machine". By this, Ryot believes that it can use VR to surround the viewer with realistic images of news worthy events – like the Syrian civil war. With the enhanced viewer experience, Ryot hopes to engage viewers and help shape public opinion.

And, it's not just Verizon that's investing in production capabilities. In June, 2016, Comcast led a $7 million investment round in Felix & Paul Studios, a Canadian based creator of VR films that has produced stories for Facebook, Universal (owned by Comcast), and Fox.

## Using VR and AR to Enhance Existing Businesses

Beyond these early stage investors in VR technology and VR production assets, several other media and entertainment firms are experimenting with the technology within their core business. Key examples include Six Flags and Live Nation.

Six Flags – a U.S. based regional theme park operator – has taken a roller coaster in Georgia and augmented it with VR. In partnership with Samsung Gear VR and Oculus, the Dare Devil Dive coaster has been equipped with wireless headsets. Guests that use the headsets will experience images that are synchronized with the coaster's movements in a fighter aircraft simulation.

**Figure 76. Six Flags Roller Coaster**

Source: Six Flags

Live Nation – the largest concert promoter in the world –signed an agreement with NextVR in May 2016. Under the terms of the agreement – which spans five years – Live Nation will broadcast hundreds of upcoming concerts in virtual reality. NextVR believes concerts are a natural venue for VR for two reasons. First, most concert patrons want to be in one spot: right in front of the stage watching their artist of choice. That makes camera placement relatively easy. Second, a significant part of the concert experience revolves around sound, not images. And, that makes it technically easier for NextVR to offer an ideal VR concert experience.

**Figure 77. NextVR VR Music Concert**


Source: NextVR/Live Nation

We don't mean to suggest, however, that VR content can be universally applied to all types of content. There are, of course, limitations. Here are a few:

1. First, the VR cameras that are used to capture the content are large. This limits their ability to be mounted on umpires, players or in tight spaces. As such, for sporting events, the cameras are usually placed off-field. And, since on-field VR viewing – at eye level with the players – isn't very enjoyable, this severely restricts VR content for many popular sporting events like soccer, U.S. football and baseball. But, for sporting events with a unique line of site or tight spaces – like Formula One or boxing – VR can be enjoyable.

2. Second, current VR equipment cannot zoom. This also poses some limitations for content that requires frequent interplay between wide angles and close-up viewing.

3. Third, VR recording equipment is still expensive. As such, beyond the normal experimentation that's going on today, the cost will need to come down considerably before VR recording goes mainstream.

4. Fourth, VR headsets can still be a bit cumbersome. Because of this, consumers will need to see the size and cost diminish before VR viewing can be considered easy for the typical consumer.

Even with such limitations, make no mistake. Entertainment companies – from Disney to Comcast to Verizon – are investing in VR hardware and VR production assets and layering in VR into their core businesses from concerts to theme parks.

## A Conversation with Neil Graham, Executive Producer, Sky VR Studio

**Thomas A Singlehurst, CFA**
Head of European Media Research

*Neil Graham is Executive Producer at Sky VR Studios. Sky VR Studios was set up in 2016 to create VR content for the group. Sky is planning on launching its own Sky VR app in October 2016. We talked to Neil about his views on the medium and Sky's ambitions for VR medium term.*

Neil Graham is Executive Producer at Sky VR Studios, the dedicated in-house virtual Reality (VR) production unit established by Sky in 2016. Neil is responsible for the creation of immersive Virtual Reality experiences across news, sports, and entertainment, leading a team of directors and production staff with rare and valuable experience of VR film making.

Neil joined Sky in 2005, and has held a number of roles across Sky Movies, most recently as Executive Producer for Sky Moves and On Demand, working on the latest broadcast technologies, including 3D. Before joining Sky, Neil worked for Mersey TV.

### How long have you been involved in VR?

*When I first started looking into VR about five years ago, we got very excited about the opportunity in 360-degree cameras but the back-end technology wasn't there and dragging a picture around a desktop with a mouse was a very clunky experience.*

*Two or three years ago, with the advent of tablets and smartphones, it became a bit more interesting but finding cameras that worked was a challenge. The reason we are doing it now is because all of that technology has come together in a way that we can actually make use of it in all those different areas.*

### How different is VR as a medium to work in for a content creator?

*It is a completely new medium.*

*TV and film directors and content creators who are used to having control of a single 40 degree frame and are used to having the control of knowing that at any one point they can cut to a different angle, they can cut to a different frame, cut to a different person. They can control everything in post-production. You don't have that same ability with virtual reality. It's completely new.*

*With VR, it is a bit more like theater. You have to block everything out, tell everyone what they are going to be doing and, for the most part, get out of the way. There's only really one blind spot in the room and that's directly underneath the camera.*

*The grammar for VR storytelling is still being written at the moment. I don't think, in terms of drama and storytelling, there has yet been a single piece of content where everyone says "Yes, that's the one. This is how VR works. I completely understand it now. The future has been written".*

### What is your take on how VR alters the consumer experience?

*The reaction you can get by placing someone at a sports event or onstage at a concert – just somewhere where they haven't been before, like on the touch line of a football event or on the corner of a boxing ring as Anthony Joshua becomes World Champion – the reaction you get from that is completely new and it is compelling enough to last.*

*That said, it may end up a complement to traditional TV rather than a substitute. If you're watching a Coldplay concert and you have a simultaneous VR stream – you may not necessarily want to sit for two hours with a head set on. But if you are watching it on TV and your favorite song comes on, you can put your headset on and be standing right beside Chris Martin onstage. I don't think this is the kind of second screen experience that would be lost after the one or two "wow factors" when people are getting used to it. It is a really interesting use of the medium.*

**Figure 78. Anthony Joshua Becoming World Champion**

Source: Sky

Figure 79. Leicester City VR Image

Source: Sky

### What are the limitations of the format?

*The main limitations we find are twofold: one is the tools that we have to create VR, in particular the hardware. But if we spoke again in three months those limitations may well have dropped away considerably, and in six months or a year, even more so. We are continually visiting tech events hunting for the very best VR cameras, ones that will take a large amount of the leg work out of the post-production.*

*There are also limitations at the moment in terms of the resolution in which you can watch VR content. We are future proofing all the content we are doing by shooting in 4K, but the headsets are effectively two magnifying glasses on a screen with loads of pixels on it. We need to improve what can be done.*

*Beyond that, however, some people might say that the fact that you can't zoom and you can't cut in the same way that you can with traditional film is a limitation to storytelling, but I don't think it is because it is a completely new form of storytelling. In the same way that cinema was a new form of storytelling when people had been used to theatre for thousands of years, this is a new experience.*

*That's why it is important to have lots of content creators working together now, because the technology companies have got the technology to a stage where the industry and consumers are ready for it. But I think it is now content creatives that will drive the next wave of improvement.*

### Why as a pay TV company has Sky taken such an interest in VR?

*It's the combination of Sky being a content company and an innovation company. On the content side, we have got access to the best sporting events, the best cultural events, to Hollywood movies, to dramas, entertainment and news. Meanwhile on the innovation side, we have always looked at ways of engaging customers and bring them closer to our content.*

*Because there are a number of potential uses for VR in each genre – and we've explored lots of them over the last 6 months – there is a very clear reason for us to get into it because we are offering our viewers an experience that is not only additional but completely new.*

### What is the scope and scale of what you can achieve with the VR Studio setup?

*To be honest, I don't think we know exactly what the scope and scale is at the moment. Certainly the way the content production division is set up, we wanted to learn properly how to produce VR content to begin with.*

*We are also not saying that this is something that we can do exclusively by ourselves. With this in mind, last month we announced we are also going to start commissioning a small number of high-end VR films.*

*The aim for us is to work out what the best uses of VR are in terms of storytelling and covering different areas, but also how to produce and commission content that consumers want to engage with. We also want to learn about all the relevant technologies by working with as many technology partners as we can.*

*In short, we want to be the home of high quality VR as well as one of the key players in driving the medium forward and writing the grammar of VR story telling.*

**Figure 80. David Beckham Behind the Scenes at VR Studio**

Source: Sky

### Is VR a complement to or a substitute for the longer term?

*For the foreseeable future, people won't stop watching TV and start watching VR. It is a completely different experience.*

*Having said that, since we set up we have been having a lot more conversations with the various teams within Sky on areas where VR suits either an existing project or where there could be an interesting VR idea that comes into us that we could use to drive a project that is on screen traditionally.*

*One example is a piece we have done in conjunction with Sky Arts on the English National Ballet. The English National Ballet have a new production of the classical ballet Giselle. That production is being choreographed by Akram Kahn – an Indian modern dance choreographer who did the opening ceremony of the London 2012 Olympics amongst other things. When we looked at the traditional ballet, we discussed a VR idea where we took the ballet off the stage and created a really*

*unique, immersive VR dance experience. It is a small segment of the story of the ballet and it is just the one main dancer who is choreographed around the camera, and as she is dancing, light and dust trails are coming off her limbs and leaving patterns where she has been dancing.*

*I don't know whether you have seen Google Tiltbrush on the HTC Vibe, where you can pick up controls and paint in the air. It is a performance version of that kind of experience. In this case, the VR experience will precede Sky Arts' coverage but it is a useful example of what we want to achieve. It is in part promotional but also very satisfying additional content if you are a fan of the arts.*

*It will end up working both ways. We are commissioning original VR films, but in the films we are commissioning, we are looking at existing intellectual property (IP) and working with existing content creators and directors to work out where the synergies are and work out how they complement each other.*

### Is Sky thinking about the VR app as an injection of value for existing customers or is it a potential paid for product in due course?

*The app is going to be available for free when it launches in October. At the moment, the goal is more to get the word out there that VR is here. A lot of VR content sits with companies like Oculus, Weaver and Jaunt; companies that aren't well known beyond tech consumers and aren't well known for content. So what we are doing at Sky is taking a content brand and getting the word out there and hoping that that message will give us the feedback that we need for future VR content production. This will allow us to better assess what VR is going to be. We are not at a stage where we are able to think about it as an additional product because we haven't yet fully harnessed what it is. It is an experimental phase.*

### It sounds like the VR ecosystem is very collaborative?

*Selfishly from a content perspective, the partnerships that we have with all of the tech companies really help us. It helps us learn how to move our content forward. It helps us to speak to Google and Facebook and Oculus because we can get their learnings and get up to speed very quickly. And vice versa, they will probably learn a great deal from us as a content company. From my perspective, our partnerships have been very useful – it has been very collaborative and that certainly helps.*

**Figure 81. The Sky VR Google Cardboard**


Source: Sky

**Focusing on some of the technical aspects of VR production, who provides the most reliable authoring/operating systems?**

*Almost everyone is working with Unity and it is an amazing platform. Recently we were going to do our first reconnaissance and test shoot on a VR film in Egypt, but we couldn't go on the weekend we were planning because of security risks. We wanted to keep the project going, so we went to one of our Unity designers and he built Tutenkhamun's tomb in Unity to the millimeter and we animated sweeping exterior shots coming down using the this platform. It is an incredible tool, as is Unreal.*

**And on the hardware side, does it make a difference to you whether people use smartphone or PC-based HDMs?**

*The ultimate goal is to have the Sky VR app available on all hardware whether it is HTC Vive, Oculus Rift, Samsung Gear or Google Cardboard. That's actually really important because a number of the hardware companies have done content deals or created content themselves where they have a walled-garden approach, so as a viewer if you are switching between different platforms you don't know which content you are going to be getting on the different headsets.*

*In terms of moving the adoption forward, ideally we would produce everything for HTC, Sony PlayStation VR and Oculus Rift because that's the best experience and you don't have the resolution problems and it is just a much higher-end experience, but the mobile adoption is really important.*

**What are you most excited about that's coming up in the space?**

*We are eagerly awaiting Google Daydream and are also waiting to see what Apple do. But whatever happens, the next generation of phones will be built for VR, as the Daydream platform will be, and then at least we won't have the issues around having to produce different resolutions for different headsets.*

*Longer-term, I am also very excited about crossover/mixed reality headsets where you can switch between VR and AR. One of the problems that people often come up with VR is that it can be isolating and lonely when you put the headset on, even if it is a very immersive experience. With mixed reality/AR, however, you and your friends could put headsets on and watch a football match on your coffee table. It will be a great way to augment your existing world.*

## Movie Theaters

**William Yang**
Greater China Technology Hardware Analyst

In the Cannes Film Festival held this May, Starbreeze, a Swedish high-end VR entertainment content and hardware provider, made an announcement it was setting up a partnership and joint venture, known as StarVR, with Acer. Later in May, the partnership further extended and IMAX also joined the fray.

What are the roles of the three in this partnership? IMAX will build VR experience location-based entertainment centers (mainly theaters), Acer will provide hardware (including StarVR head-mounted display and PCs) to the VR centers through 2016-17, while Starbreeze will co-create VR content with IMAX and will rely on Acer for hardware manufacturing. Currently, most VR content providers focus on games, and we see this partnership as the first one focusing on movies.

**Figure 82. StarVR Headset from Starbreeze**

Source: StarBreeze

IMAX

IMAX is the most aggressive among its entertainment peers in promoting 3D movie content and has built 3D cinemas worldwide. It is successfully perceived by audiences as the leading provider in 3D cinema experience. Several of the films that are presented in IMAX 3D include *Avatar*, *Gravity*, *Jurassic Park*, and *The Amazing Spider-Man*, and many more.

IMAX deems VR to be a major key in leveraging their brand and recognizing their know-how in immersive entertainment experience. According to IMAX management on the July 2016lresults call, "…*We aim to use the next 12 months to 18 months to build a strong pipeline of VR content and to create a lean-enough business model that we can license to our business partners on a global basis beginning in 2018."*

Starbreeze / StarVR

Starbreeze's flagship game title is *The Darkness,* initially released in 2007. Beginning in 2014, Starbreeze started development on started to its StarVR headset. Key specification differences between StarVR headset and its peers' (Oculus Rift, HTC Vive) are: (1) higher resolution (5120x1440); 2) wider screen (5.5" x2); and 3) different viewing angle (210 degree). It is targeting the professional- and location-based market, mainly theaters, theme parks, and others requiring professional VR experience, such as pilot training.

As a game publisher, StarBreeze has already published a VR shooting game based on the TV horror series *The Walking Dead*, initially announced in 2015 at the popular Electronic Entertainment Expo (E3) held in Los Angeles. We expect it to further collaborate with IMAX on creating cinematic contents, though it will take meaningful time and money given it requires multiple 360 degree cameras, skilled actor/actresses (or high-quality animations), and massive post-shoot rendering, among other factors. To this point, Acer CEO Jason Chen commented that it takes 2-3 years to create a VR movie (⏩).

# Marketing Tool

## Hotel & Travel Agency

Using VR in marketing to promote actual consumption

Travel companies are introducing VR technologies. The most typical use case is as a new marketing tool. The use of a VR headset to display 360-degree video and photos of travel destinations around the world can provide an experience similar to actual travel. This information can then be used to help would-be vacationers decide upon an actual travel destination. We think that VR technologies have the power to drive growth in the travel industry by increasing people's desire to travel.

Marriott Hotel's The Teleporter

The Marriott International hotel chain has already introduced VR technologies. In autumn 2014, it started using its own VR technology that it calls The Teleporter as a marketing tool. It is a "4D VR" system that provides information to the five senses in addition to 3D vision. It also developed a technology called VR Room Service in conjunction with Samsung Electronics, implementing a promotional campaign that provided an immersive experience similar to actual travel via VR.

In addition to the VR special experience, The Teleporter VR system uses an individual room to reproduce slopes and sensations such as the wind that are tailored to the VR environment. The sense of smell is also stimulated. The Teleporter uses the Oculus Rift VR headset and a broad range of CG content enables VR to instantaneously transport a person to anywhere in the world, with the ultimate aim of promoting travel and hotel bookings with the virtual experience.

VR Postcard

At the same time, Marriott has started a VR Postcard service that provides its original content to guests using the Samsung Gear VR.

Other hotel, travel industry companies introducing VR

In addition to Marriot International, a range of other travel companies are trialing VR as a marketing tool.

**Figure 83. VR Usage in Travel-Related Sectors**

| Company | Summary |
|---|---|
| Marriott International | The Teleporter, VR Room Service |
| HIS | Launched VR Hawaii service |
| YouVisit | Creates 360-degree still and moving images |
| Thomas Cook | Creates 360-degree still and moving images |
| Qantas Airways | Creates 360-degree still and moving images |

Source: Company data, Citi Research

VR spreading in travel sector

We think marketing using VR will have some impact on the travel industry and will become common in the future. We also think that the range of available content will be particularly important for travel-related VR. Travel companies and airlines such as Thomas Cook, Qantas Airways, and Destination are producing high-quality VR content. At Thomas Cook's European offices, customers can experience VR video and photos before deciding to travel. There are also reports that this is contributing to sales growth.[1]

[1] https://www.vrfocus.com/2016/03/visualise-announces-vr-fantasy-flight-experience-for-thomas-cook-airlines/, http://www.bloomberg.com/news/articles/2015-06-19/how-oculus-and-cardboard-are-going-to-rock-the-travel-industry)

Will VR substitute for travel or promote actual travel?

As VR is developed further, it may become possible to feel like you have traveled without actually going anywhere. In this case, VR could have the negative effect of causing a decline in travel industry sales. However, we think that this effect will be limited in scope. VR is likely to be a valuable tool for people to obtain a sense of a travel destination and information on things to do. As the information gained from VR can be experienced more closely to reality than 2D photographs and videos, it is more helpful to actual travel than reading a guide book. We see little risk of VR being substituted for actual travel and the opportunity to feel the breeze or smell the ocean.

We think the applications of VR in the travel industry will expand. This is because it can be experienced not only in the offices of travel agents and airlines, but also in a consumer's own home or on a train or aircraft on the way to a travel destination. The big Japanese travel agent HIS has installed VR headsets in its Shinjuku office, enabling customers to experience 360-degree videos of Hawaii. Qantas Airways has installed VR headsets in its first class cabins, providing a service enabling passengers to see 360-degree vision of Sydney. It is intended to help passengers know what to do when they reach their destination.

Outlook

In the case of places that cannot normally be visited in reality, travel using VR is not useful for marketing, but travel services selling the VR experience itself may be possible. Examples include simulations of the summit of Mt. Everest or the depths of the ocean and space. Using VR technologies would enable a highly accurate travel-like experience to destinations that cannot normally be visited. This could be possible if the quality of content improves.

Proxy travel

While we do not think VR will work against actual travel, there should be room to question this possibility in the long-term future. Technological advances may make the proxy experience increasingly like the real experience. In the long term, it may become possible to teleport to a different place and feel as though you are really there.

This feeling is called tele-existence. The VR images are live images and the camera has robot arms and legs that substitute for the person's limbs. If not only vision and sound but the movement of the ground and smells can also be communicated, it may be that the user will no longer be able to doubt that they exist in the world that they are experiencing via VR.

## Sports

VR experience from first row of seating or within field

People are drawn to live action experiences such as watching sporting matches. Services that offer the opportunity to watch sport at home but with a real sense of immediacy have begun to crop up. We expect an increase in 3D sports broadcasting that enables a user to wear a VR headset and by moving their head see the 3D vision move also, thereby allowing the user to watch a sporting match as though they are in the front row of seating. There is also research into VR that would place cameras inside the playing field, so that the audience feels like it is actually participating rather than just watching. Trials of such innovative technologies may be implemented at the 2020 Tokyo Olympics.

Who are the main providers?

Next VR, a Californian company involved in the live streaming of VR video content, is distributing sports VR video. The company has specialized technologies for the live streaming of VR content, and its tie-ups with the big broadcasters, event promoters, and sports teams enable it to lead the industry in the accumulation of experiences in the live streaming of VR images of sports and music events. Japan's SoftBank and China's CITIC invested in Next VR in 2016.

In 2016, Next VR formed an alliance with the major US nationwide TV network Fox Sports. It also announced plans for VR broadcasting of sports events for which Fox Sports holds broadcasting rights under the agreement.

**Figure 84. VR at the Front Lines**

Source: Next VR

NBA on VR

Next VR has also formed a partnership with the NBA and started providing an experience similar to watching a game live in the arena. The company broadcasted VR content for the NBA regular season and the NBA All-Star Game in 2013–2014.

The size of the court and the ball in basketball makes it a good fit for VR technologies, as lines of sight are good and the sense of realism strong. In addition to enjoying the game, the halftime show is also fun to watch. The excitement of nearby fans is also evident.

**Figure 85. NBA VR Imaging via NextVR**


Source: Next VR

Next VR formed a partnership with RSE Ventures (a sports and entertainment multinational venture company) to broadcast the December 2015 International Champions Cup on real time VR. The company's CEO Brad Allen says he wants to deliver to fans an experience similar to watching the world's best athletes in action from the sidelines. These broadcasts can be viewed with the Samsung Gear VR.

**Figure 86. Live VR Transmission at the ICC via NextVR**


Source: Next VR

More casual sports VR also

The Japanese professional baseball team the YOKOHAMA DeNA BAYSTARS is using the Samsung Gear VR to offer a 360-degree video content service, the 360 BAYSTARS. The content does not enable the watching of a live game, but users can watch VR video from a perspective close to that of players selected by the team and see VR vision from close to the baseball field. The team says it wants to provide the VR experience to people who are unable to make it to the baseball stadium.

**Figure 87. 360-degree BAYSTARS image**

Source: YOKOHAMA DeNA Baystars

Players using VR in training

In the world of sports, VR is being used by professional athletes and fans alike. An initiative to use VR in player training has started in American football. STRIVR Lab, which started as Stanford University's VR research facility, is a pioneer in this field.

When athletes and their coaches are researching opponents, one useful method is to watch video of past games or matches. Using VR for this improves the quality of the simulation. Reliving a match via VR is one example, and this training is particularly effective for American football quarterbacks. As the leader of the offense, quarterbacks are required to have a broad field of vision and superb judgment, so practicing and reliving past games with a strong sense of realism enables them to examine their own movement in greater detail.

Stanford University started research into the appropriate video and methodologies in 2007, and STRIVR Lab was established in 2015. The company has conducted research in conjunction with the Stanford University football team, and already 12 universities use the training program it has developed. Five NFL teams have also introduced VR into their training camps. The company also plans to expand the applications of the system to basketball and ice hockey.

Outlook

Being able to experience a live game via VR as if one were actually in the stadium is likely to appeal greatly to fans who are unable to visit the stadium in person, and could lead to the development of a new market. Essentially, using VR for games and matches could be likened to selling 10,000 ringside tickets to a boxing match or creating 20,000 courtside seats for an NBA game. . Advances in VR technologies should enable a viewer to watch from a player's own viewpoint, making it feel like they are actually playing the game. This, too, could drive the development of new markets as part of disruptive innovation.

We think that sporting and musical events are highly compatible with VR and AR. In these industries, there has been much progress made in how viewers consume entertainment, such as public viewing. We think that VR and AR are technologies that will drive these developments into the next dimension.

**Figure 88. VR/AR in Sports**

| Title | Link |
|---|---|
| DeNA | https://www.baystars.co.jp/360/ |
| Next VR | http://www.nextvr.com/#/<br>http://uploadvr.com/nextvr-raises-80-million-live-streaming-sports/<br>http://www.roadtovr.com/fox-sports-and-nextvr-sign-five-year-vr-broadasting-deal/ |
| STRIVR Labs | http://www.strivrlabs.com/ |
| Soccer ICC | https://www.vrfocus.com/2016/07/nextvr-announces-vr-schedule-for-icc-matches/<br>http://vrscout.com/news/watch-real-madrid-vs-chelsea-live-vr/ |
| F1 | http://www.si.com/edge/2016/04/05/sports-virtual-reality-next-vr-device |
| NBA | http://www.roadtovr.com/watched-nba-game-next-vr-never-want-go-back/ |
| Others | https://backchannel.com/how-vr-will-change-sports-and-how-it-wont-e2d1caa47700#.vyrkhaqb3<br>http://techon.nikkeibp.co.jp/atcl/column/15/052000044/071900010/?ST=tomhel |

Source: Company data, Citi Research

# Automotive

## Enhancing HMI: HUDs and Augmented Reality for Automotive

**Itay Michaeli**
U.S. Auto & Auto Parts Analyst

The heads-up display (HUD) concept has been around for quite a while, as the first known automobile HUD went into production with GM in 1988. From that point forward HUDs have been a very niche product, mainly due to size, cost, and benefit constraints. With recent trends of infotainment, a more focused effort to improve safety by helping to keep eyes on the road, the declining cost of components, and the reduced size of components/end system, this niche product is on track to become a more mainstream product that is widely accepted by many vehicles. Factor in the evolution of the HUD to encompass augmented reality, and you have an explosive growth product within the global automobile industry. HUDs can either be in one of two fittings: (1) windshield HUD (currently the only one with real production volume)—a HUD that projects information directly on the windscreen of the vehicles; and (2) a combiner HUD, which projects the information to a separate piece of glass or plastic, known as the combiner.

Windshield HUDs, as shown below, project directly to the windshield, with no combiner piece. The average selling price (ASPs) on windshield HUDs (as per an IHS survey) carry a premium of 2.3x combiner HUDs, even as the volume mix shifts

The Cadillac CT6, unveiled at the NYC Auto Show, has a windscreen HUD

**Figure 89. Evolution of Windshield HUDs**


Source: Continental

**Figure 90. Example of HUD-AR: Pioneer AR Navigation system**


Source: Pioneer

Combiner HUDs shown to the right – this feature can be added to a MINI Cooper for $500

**Figure 91. Combiner HUD Display**

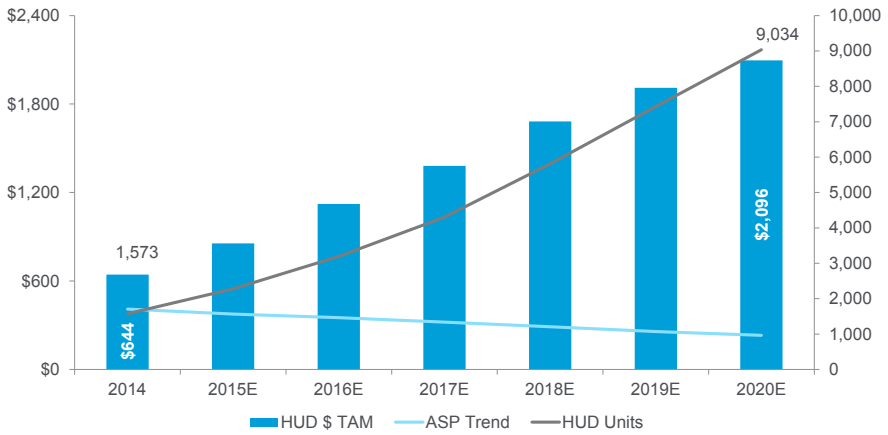

Source: MINI

Sizing up the markets: The current and the future

The overwhelming majority of HUDs currently produced are windscreen HUDs, which typically carry an ASP of ~2.3x more than combiner HUDs. In sizing up the market we believe that units (1 unit per vehicle) are expected to grow at a 2015E-2020E CAGR of ~30%. At the same time, the revenue TAM is expected to grow to nearly $2.1 billion.

As expected, North America, China and Western Europe remain the most important regions for both unit TAM and revenue TAM, accounting for 75% of the total TAM in 2020E

**Figure 92. HUD Market Overview: Revenue TAM, Volume, ASP**

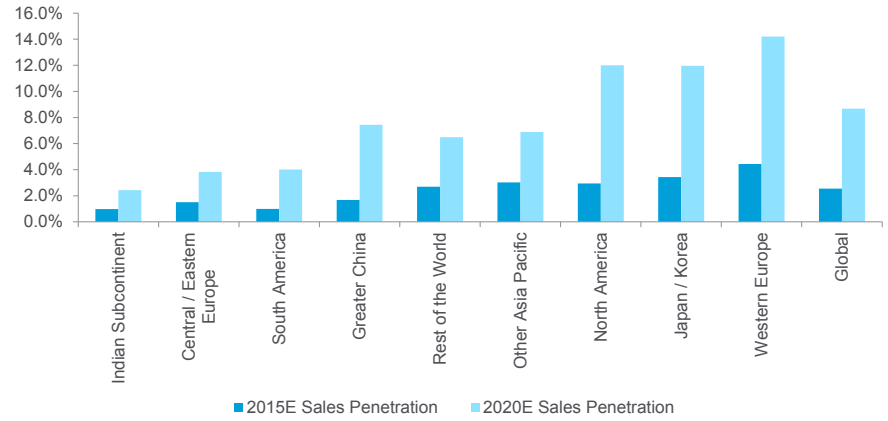



Source: IHS, Citi Research

North America, China and Western Europe remain key regions for adoption of HUD technology

By 2020 it is estimated that overall HUD penetration will be ~9%. The major regions adopting this technology are no surprise – W. Europe, Japan/Korea and North America remain the highest regions by percentage of sales adoption.

**Figure 93. Global Sales Penetration of HUDs (Windshield + Combiner)**

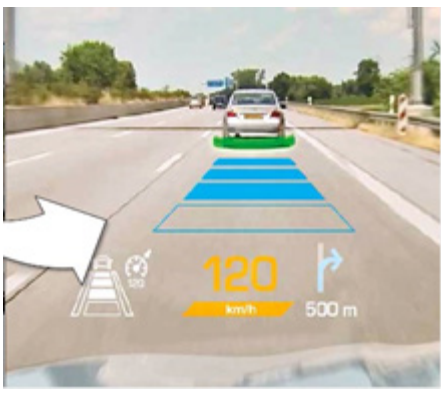



Source: IHS, Citi Research

A further step to the future…augmenting reality

A key feature of HUDs is that the very nature of the product allows for OEMs to leverage it as an ideal platform for multi-modal technological convergence. What we mean by this is that as the infotainment and active safety megatrends continue to develop, they will eventually converge to a point where all information will be available and accessible in one place, allowing for faster adoption and increased penetration. For HUDs, this can be achieved by leveraging the prime real estate within a vehicle to not only display driver information, but also provide active safety cues to help the driver gauge potentially troublesome situations, or provide navigation and other directions in one easy-to-view location. We already know the trajectory for both windshield and combiner basic HUDs, but the next step in the evolution of the HUD is to augment the reality of the driver's viewpoint, allowing for 3D effects to cover the depth of the scene ahead. The 3D aspects of the augmented reality will not only help the driver minimize distractions and help keep them focused on the road, but it will also help to reduce the uncertainty of the road ahead. As seen in the images below, the augmented 3D reality is able to help enhance both infotainment (real time navigation becoming part of the road) and active safety technology (3D distance between cars to help prime AEB or ACC) into one easy-to-view graphical user interface (GUI)/HMI.

**Figure 94. Augmented Reality HUD: ACC**




Source: Continental

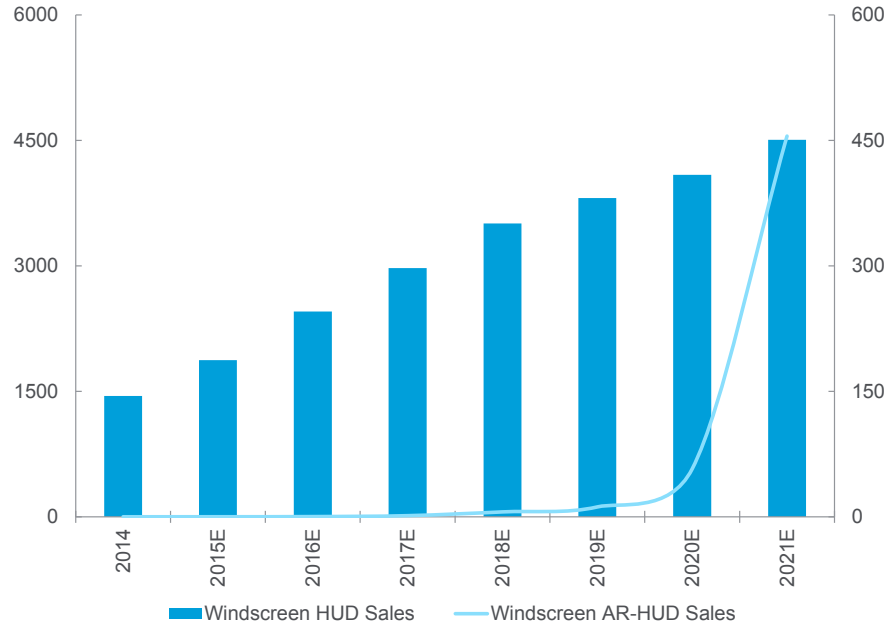
**Figure 95. Augmented Reality HUD: NAV**

Source: Continental

Augmented reality HUDs (AR-HUDs) will all start off as windscreen HUDs, and will be at a premium relative to the typical windscreen HUDs; the exact ASP of these AR-HUDs are currently unknown as only very limited shipments are expect to occur from 2015E to 2019E; from 2019E through 2021E unit shipments should ramp significantly, driven by increased penetration relative to standard windscreen HUD shipments, but will still remain a niche market. As the windshield technology does carry a much higher ASP versus combiners, we believe unit shipments will likely remain low as these costs could be a headwind to more mass market adoption, thus limiting this technology primarily to luxury vehicles at first. By 2018 we estimate that 3.5 million windshield HUDs will be shipped, of which a mere estimated 5,800 units will have some type of augmented reality. This number of units could reach 455,000 by 2021 or about 10% of total windshield HUD unit shipments (or ~0.4% of global sales).

A small, but hyper-growth market

**Figure 96. Windshield HUD Sales (LHS) and Windshield AR-HUD Sales (RHS) / Windshield AR-HUD Sales are Included in the Total Windshield HUD Sales**




Source: IHS, Citi Research

As HUDs are very software-driven product platforms, we tend to favor this technology in our "Car of the Future" investment framework. Additionally, this software-heavy solution should allow for higher margins and higher ASPs on future iterations of these products—for example, any increased penetration of AR-windshield HUDs in favor of typical windshield HUDs would help expand the revenue TAM for total HUDs.

## Applications in Education

Next-generation learning methods about to take hold

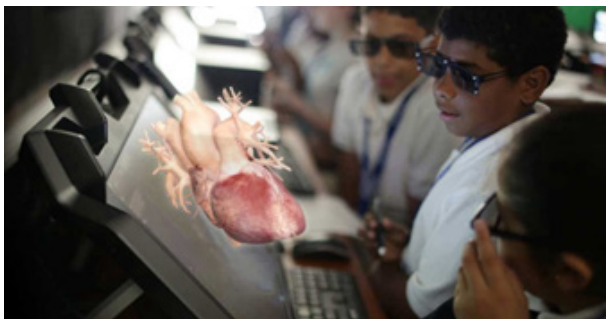
VR/AR is starting to be incorporated into educational settings. It is said that people can remember things more accurately through experience than they can by reading text or listening to speech. VR/AR is a means of experiencing virtual reality in a natural and direct way, and is unlike looking at things on a page or projected on a flat screen. We think it will take hold as a next-generation learning method.

The use of VR/AR makes possible experiences such as visiting ruins or other famous sites, looking around museums, and being under the sea or in outer space, all possible while sitting in a classroom. Because VR/AR imparts a greater feeling of reality than photos or 2D video, it enables, for example, the user to look up at Dubai's Burj Khalifa from directly below and get a true sense of its size. Using VR/AR to experience things from the past and future, as well as being transported to outer space or under the sea, is likely to become an entirely new learning method. Another example of VR/AR at its best is the way it can be used to impart a three-dimensional understanding of structures such as the human body and buildings. VR/AR unlocks deep meaning unimagined for many years as well as complex physical structures.

Many education-related VR/AR companies have clear objectives, are at practical-application stage

Examples of VR/AR being introduced in the education field are growing steadily, and there are now many related companies with clear concepts. Among the standouts in the STEM (science, technology, engineering, and math) field is zSpace, a company founded in 2007 and based in Silicon Valley. zSpace specializes in STEM. It is said that in the fields of science and math, it is difficult to deepen one's understanding through the printed page, whereas VR/AR makes breakthroughs highly likely.

**Figure 97. Experience and Understand Objects in Three Dimensions**



Source: zSpace

**Figure 98. Enabling Breakthroughs in STEM Areas**

Source: zSpace

zSpace offers a service in which virtual classrooms—designed specifically for students ranging from elementary school to high school— are installed in schools. In these virtual classrooms, students wear 3D glasses and use specialized pens to operated dedicated computers and dedicated displays that project images of 3D objects seemingly into empty space. Students see physical objects appear to float up from the screen into three dimensions, allowing them to examine the objects in their entirety by rotating them up/down and left/right. This makes possible the kinds of educational experiences in the STEM field that are difficult to have in the real world. To date, around 100 school districts in the U.S. have installed zSpace's virtual classrooms, and the company's products are scheduled for introduction in other countries as well.

Numerous education-related VR/AR companies being launched

A number of companies other than zSpace are starting to make progress in their education-related VR/AR efforts.

Nearpod provides content that enables students to go on field trips in virtual space. The company's product also allows teachers to easily create their own VR teaching materials, enabling them to incorporate their classroom objectives and their students' requests.

Immersive VR Education also provides content, but specializes in enabling students with experience in VR to learn about objects through role-play. For example, the company's service allows students studying history to experience being part of the Apollo 11 crew, and being the first person to land on the moon.

Universiv, another company providing VR-based education, believes that the platform is as critical to education and study as it is to entertainment, and highlights statistics showing that students remember 20% of the information they hear and 30% of the information they see, but 90% of the information they receive through activity or simulation. It believes that VR is thus optimal for various types of study.

There are also problems in education-related VR/AR. It is said that small children are at risk of becoming cross-eyed if they look at video on a twin-lens VR viewer. This problem will be difficult to solve quickly, since it is closely related to the mechanics of VR/AR. In the near term, we think VR/AR may have to be viewed as an education tool for students above a certain age.

## Medical Equipment

Relatively speedy commercialization of VR/AR in the medical treatment field

We believe VR/AR has significant potential in the medical treatment field, mainly in two areas. One is the use of internal body VR during diagnosis and treatment to better understand the condition of the patient. The other is the use of VR and AR for training, for example, for simulated surgery before actual operations and for general medical training to improve skills and knowledge. VR/AR is gradually being employed in both areas and we believe it could have a real impact on the medical industry relatively quickly (in the next 5-10 years).

Looking inside the body with VR

Inserting a miniature camera into the body and viewing the images taken with a VR headset can allow physicians to gain a better understanding of the shape and condition of affected tissue and improve treatment efficiency. The camera must be able to take 360-degree images and transmit the minimum amount of data required, but also be small enough not to place any strain on the body. The hurdles are high, but we believe the technology can be realized over the medium term. That said, laparoscopic surgery using hard endoscopes and other common non-invasive surgical technology is likely to advance further in the near term. Long-term, we expect detailed surgical treatment and drug administration to be performed while watching VR images.

**Figure 99. Doctors Will be Able to Look Inside Body**

Source: 123RF

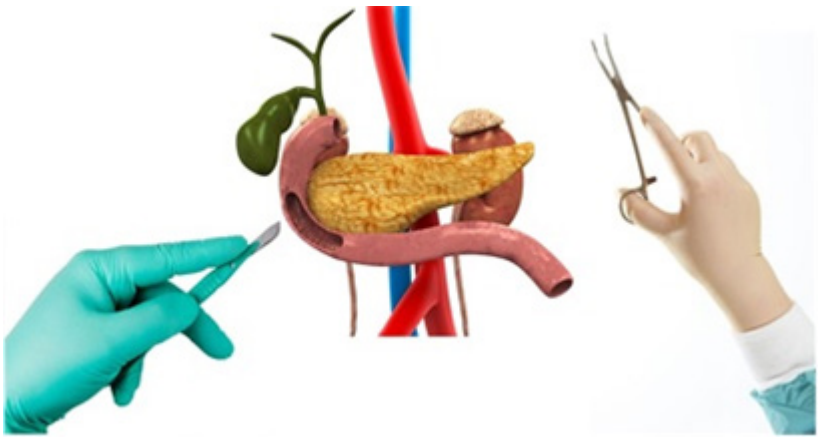
Using AR to project the patient's body image

Early-stage VR/AR technology for medical training is being trialed. Internal organs are superimposed on a screen or dummy as a reference before actual surgery. Many operations take a long time and parts of the treatment strategy and process are often not decided until after the incision is made. The more information that can be ascertained before surgery, the higher the chances of a successful operation. Longer-term, we believe VR/AR technology will be able to project a broader range of body parts and live video could be used in surgery. VR should contribute to the quality of general training.

**Figure 100. Organs Through the Body**

Source: 123RF

**Figure 101. Where to Cut and Clip Before the Real Operation**



Source: 123RF, Citi Research

VR applications are being used in mobile rehabilitation systems for stroke victims…

With stroke already a frequent cause of adult handicap in Western countries, our aging population and increased survival rates for stroke patients makes neuro-rehabilitation very important in a patients desire for a normal life and VR is now being used in early motor rehabilitation. Neuro-technology start-up Mindmaze raised $250 million earlier this year to fuse VR with healthcare. Their MindMotionPRO technology "can be used early in the recovery process to trick the patient's brain into believing that immobilized regions of their body are still working, thereby spurring the recovery to take place." This easy to use mobile rehabilitation system is designed for bedtime mirror therapy using VR, computer graphics, brain imaging and head, hand and finger tracking. The technology includes a database of immersive VR exercises and personalized exercise regimes are prescribed. VR provides a highly stimulating environment compared to traditional rehabilitation treatments and as a result, clinical experience has demonstrated increased patient engagement and longer training times.

…and also by psychologists to treat anxiety disorders

VR has also been shows in controlled studies to be effective in the treatment of anxiety disorders. This includes post-traumatic stress disorder (PTSD) to help the sufferer adjust to their symptoms and develop coping strategies. Psious, a Spanish and American behavioral technology company, provides mental health professionals with animated and live environments they can use in their clinical practice when treating phobias. For example, a patient suffering with acrophobia (a fear of heights) can be placed in a VR setting where a solid high barrier on a balcony is changed to be glass, is then lowered in stages and ultimately removed. Each scenario is designed, supervised, and tested by psychologists and can be adaptable to each patient. Ahead of acrophobia, on the top 100 phobia list (from fearof.net) includes ophidiophobia, with nearly a third of the adult population said to have a fear of snakes, and arachnophobia (a fear of spiders).

## Factory and Industrial Use

NEC's ARmKeypad: AR-related

The Japanese IT services company NEC has developed AR software that is useful when using measuring equipment. By combining an AR headset with a smartwatch, it is designed so the user can see CG through AR glasses. A keyboard and switches are displayed on a worker's arm, and these are used to control the actual measuring device. It is not a semi-transparent hologram, but rather shows a clear keyboard attached to the arm via CG. The camera sensor on the AR headset and accelerometer in the smart watch are used to recognize the movement of the fingers when using the keyboard.

The system will be particularly useful for workers who need their hands to remain free, such as facility inspectors, home delivery drivers and healthcare professionals. There is no need to stop work in order to pull a device out of one's bag or pocket, and the task can be completed using the virtual keyboard. This will help with the accuracy of the job, and would probably also have hygienic benefits in the medical industry.

NEC has developed the software, but says the hardware such as AR headsets and smartphones will be developed by other companies. We have not specifically included this type of software in our industry model. However, we think that the software used by AR headsets will in many cases function in this way to assist workers to do their jobs.

**Figure 102. NEC: ARmKeypad**

Source: NEC

Fujitsu's ring-shaped controller and globe-shaped sensor: AR related

Fujitsu, which is involved in IT services, PCs and semiconductor fabrication, has developed a globe-shaped sensor and a ring-shaped controller.

The globe-shaped sensor links to an AR headset, and displays the necessary information on a display according to the movement of the user's hands. The sensor on the wrist detects hand gestures, and will display information in conjunction with specific movements as well as displaying information according to what is touched using the sensor worn on a finger.

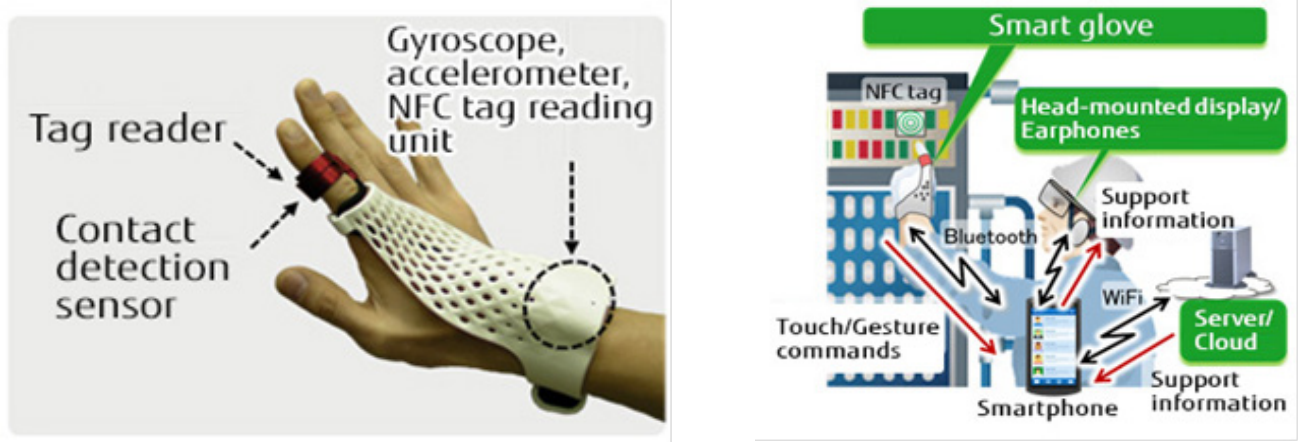
The sensor on the wrist can detect the movement of the arm so the user can, for example, turn the pages of a manual displayed on the AR headset, and has functions such as enabling a user to enter results such as "test passed" via CG using arm movement.

The sensor on the finger has a near field communication (NFC) tag reader, so if NFC tags are attached to specific objects, there is no need to supplement cameras and the like with hand and finger movement, and the information in the NFC tags that are touched can be displayed in the headset.

We expect this device to be used in manufacturing plants and for healthcare, education, and retailing. It will be most useful when it is inconvenient to take out a terminal or controller to complete a task.

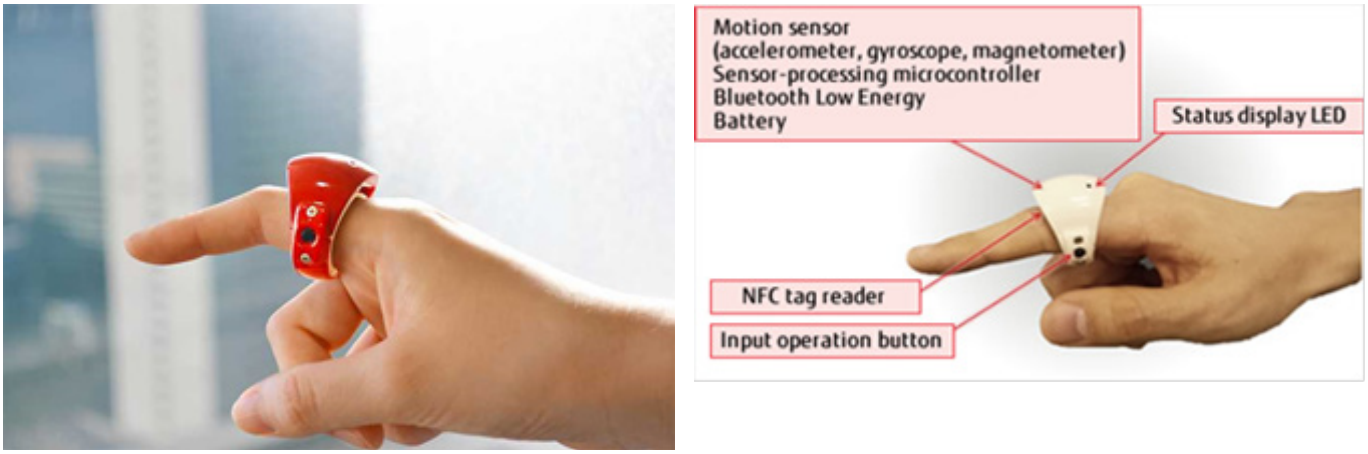
The ring-shaped terminal can be used to write words in the air without holding anything in the hand to enter letters and numbers and select information shown on the display. The fundamental mechanism is to use the incorporated accelerometer, gyroscope, and magnetometer to detect movement, but its miniaturization into a ring-shaped device enables information entry using hand and finger movement.

Figure 103. Fujitsu's Glove-Type Sensor Device




Source: Fujitsu

Figure 104. Fujitsu's Ring-Type Sensor Device




Source: Fujitsu

## Aerospace and Defense

**Jason Gursky**
U.S. Aerospace & Defense Analyst

**Jonathan Raviv**
U.S. Defense Services Analyst

As previously mentioned, VR/AR has roots in the aerospace and defense (A&D) sector. Whether it's having to land an aircraft in low-visibility conditions or fighting a war on a chaotic battlefield, seeing through "fog" has been, and continues to be, a key focus for the A&D industry. VR/AR uses are only expanding within A&D in line with the broadening commercial and consumer applications covered elsewhere in this report. Today, A&D companies innovate to offer VR/AR solutions to address unique issues surrounding safety and effectiveness. In our view, it's key to staying relevant in contemporary A&D.

### Commercial Aerospace

Mandates and structural traffic growth drive demand for situational awareness and training.

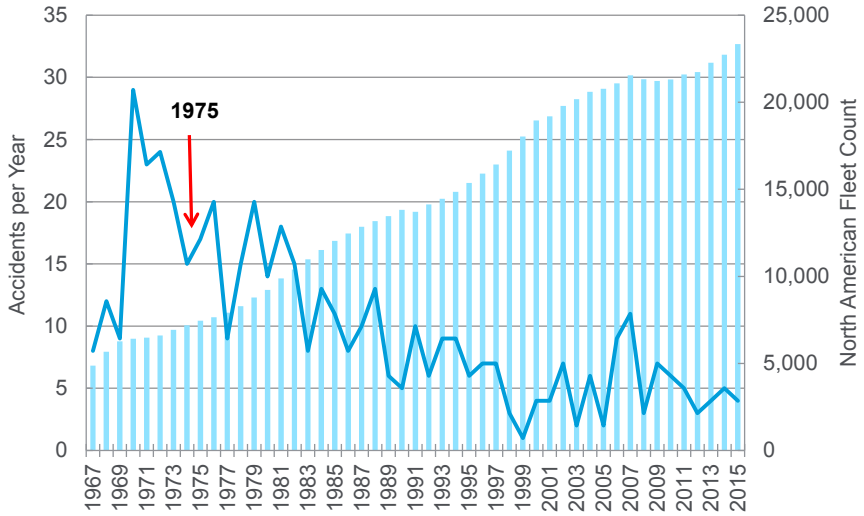
While often and easily categorized as future technologies, many of the factors incorporated into today's VR/AR innovation environment trace back to instruments used in early 20th century aviation. Tools such as the reflector sight and altitude indicator allowed for pilots to track targets or adjust plane orientation whenever visibility was poor.

**Figure 105. Altitude Indicator**


Source: Photo courtesy of L-3

Combatting poor visibility and improving operator situational awareness continue to be key issues. As a result, commercial aero VR/AR applications are focused on avionics and training/simulation, all with an eye towards improved safety, as the skyways are becoming increasingly busy and challenging to navigate and with >85% of aircraft accidents stemming from pilot error, according to the Center for Aviation Insurance. As shown below, we highlight 1975 as the year in which HUDs began to see widespread commercial use and their impact on operator awareness and flight safety (among other safety-enhancing technologies).

**Figure 106. Aviation Accidents have Fallen Precipitously as a % of the In-Service Fleet**




Source: NTSB, Ascend (all based on North American operators)

Several A&D companies offer HUDs as standard equipment on new-build commercial aircrafts or as retrofits on older aircrafts to address safety mandates. China is a good example of a country experiencing rapid growth in air travel despite a persistently restricted airspace. To that end, regulators have mandated HUDs for commercial aerospace operations, creating a market that companies like Rockwell and Thales are pursuing. It's notable that their offerings are at least party built on experience providing HUDs for military platforms.

**Figure 107. Rockwell Collins HUD**

Source: Rockwell Collins

The industry also needs more pilots as commercial air travel continues to outgrow GDP based on structural growth in very large, emerging markets like China and India, where air travel is still under-penetrated. For instance, Boeing forecasts that the industry will need 617,000 new commercial airline pilots through 2035, not to mention 679,000 maintenance technicians and 814,000 cabin crew. These personnel needs lend themselves to various training solutions, many of which incorporate VR/AR. To be sure, flight simulation is nothing new, with the need for ground-based training being made evident in the very early days of aviation. But the technology continues to develop and grow in light of the growing need for pilots, resulting in complex machines, faithfully replicating real-world flying experience from the safety of a box on the ground, potentially costing >$20 million. Companies offering pilot simulation/training technology include Flight Safety International, CAE, L-3 and Textron. Simulation plays a similarly important role in military applications.

**Figure 108. Link Flight Trainer**


Source: Photo courtesy of L-3

**Figure 109. TRU Flight Simulator**

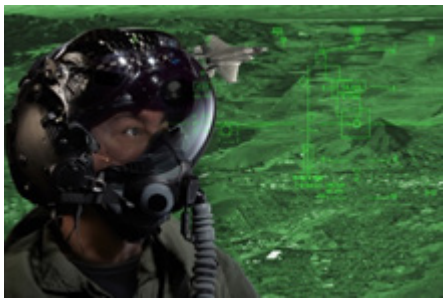
Source: Textron TRU Simulation+Training

## Military

Increasingly complex battlespaces require improved situational awareness & survivability.

These common, fundamental needs for operators stand unchanged through time, with combatants requiring more and more information to be effective. The beeping missile tracker comes to mind when thinking of a pilot's augmented reality HUD display. But the modern pilot plays a far more important role as a node in a complex communication and sensing system. Multiple feeds are pumped into their cockpit- and helmet-mounted displays, giving them increased situational awareness which in turn improves lethality and survivability. Tools include Lockheed Martin's Hydra Fusion mapping system or Northrop Grumman's F-35's Distributed Aperture System; the latter of which works with a Rockwell helmet to provide a 360 degree field of view. In other words, pilots can effectively "see through" the airplane.

**Figure 110. COL Helmet Mounted Display**

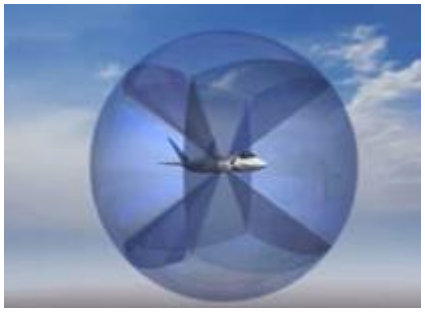


Source: Rockwell Collins

**Figure 111. Hydra Mapping System**

Source: Lockheed Martin

**Figure 112. F-35 DAS**



Source: Northrop Grumman

Meanwhile, unmanned aerial systems (UAS) are increasingly popular military tools which rely on remote-piloting facilities powered by what is partly advanced simulation technology (although it powers an operational platform in the field).

There are many applications for VR/AR in the military

VR/AR military applications also extend to the ground, as increasingly complex battlefields demand better technology to enhance safety and effectiveness of ground soldiers. Advanced soldier programs have been in existence for decades, experiencing various iterations over that time frame, with concepts often utilizing augmented reality technologies delivered through helmet-mounted displays. The most common version are night vision goggles (NVG), although today's operators use increasingly complex enhanced vision technologies provided by companies like Harris. Meanwhile, BAE Systems has evolved their traditional airborne offering to address ground applications with the Q-Warrior product. General Dynamics has also historically worked on future soldier systems.

**Figure 113. Harris Night Vision Goggle**

Source: Harris

**Figure 114. BAE Q-Warrior HUD**

Source: BAE

With the growth of realistic imaging platforms, and improved big data processing, the application of VR/AR training has extended beyond flight simulation. By giving soldiers experience in realistic, combat-like scenarios, the military has been able to reduce the cost of training while leveraging the young recruits' familiarity with game console-like interfaces.

Huge opportunity for defense services companies

Defense services companies often operate in this market, acting as contractors for the government's wide-ranging and dynamic training needs. For instance, SAIC has a "Serious Game Studio" to create new applications for homeland security, first responders, and warfighter readiness. This complements the support they've historically provided to a variety of government users such as intelligence analysts and air-traffic controllers for training applications. Leidos provides a variety of programs, ranging from training aircrews to operate Dash-8 aircraft with various sensor packages, to helping the Army plan, execute, and evaluate battle plans. CACI works with customers to provide desktop and mobile applications for teaching training and military skills, and Booz Allen Hamilton leverages a variety of technologies to help the government optimize its training and simulation programs.

# Office Use

## Software

**Walter H Pritchard, CFA**
U.S. Software Analyst

**Kenneth Wong, CFA**
U.S. Vertical Application Software, Emerging Hardware Analyst

The theoretical software applications for VR/AR are numerous as users find themselves in a more immersive user interface. Initially, high-value applications industries such as field service (a mechanic receiving real-time instructions on how to fix a car with a hologram projected to help guide the repair), healthcare (patient assessments/diagnoses), e-commerce (trying on clothes virtually) and architecture/construction (virtually walking through the proposed structure as it is designed/built) are a few examples of the many that intuitively seem viable.

We have seen vertically-focused software and technology companies take the early initiative to invest in solutions to tackle the use cases listed above. Traditional computer-aided design (CAD)/ product lifecycle management (PLM) vendor PTC has invested nearly $1 billion in IoT/VR/AR to give manufacturing customers using their Vuforia /ThingWorx solutions the ability to virtually examine, test, and service equipment and capital goods. In healthcare, 3D Systems has seen growing adoption of its Virtual Surgical Planning (Symbionix) to plan and simulate procedures. ADSK's push of building information modeling (BIM) software (Revit) and simulation software in the architecture, engineering, and construction (AEC) sector established that market as an early adopter of VR/AR, enabling engineers to explore a structure before it has been constructed. Since CAD/PLM solutions from PTC, ADSK, Dassault are used to design product and manage the content across nearly every industry, there are natural synergies for manufacturers of just about any product to use the stored "digital twin" for VR/AR purposes. We see broader applications in areas such product design, immersive customer experiences (such as test driving vehicles), and tutorials.

Applications software companies likely to benefit from VR/AR

Although, as with any new technology, initial integrations will most likely come in the form of niche applications and over time, as the VR/AR interface becomes more like cameras on smartphones (with standardized APIs), software applications will see deeper integration with existing applications. PTC's Vuforia platform has helped streamline some of the complexities here with Vuforia Studio (a VR development kit) and VuMarks (think universal product codes, or UPCs, for "things") that allow developers a customized user experience targeted at specific devices (VR goggles, iPads, etc.). Ultimately, the applications software companies will benefit the most as the new interface increases the value of the application, much the same way that mobility increased the value of some of the same applications.

We note the companies making the most investments here are in areas where there are early, viable VR/AR applications noted above. Microsoft is making significant investments here, with consumer implications first (see below) while Salesforce.com is making significant investments in order to integrate VR/AR into customer service and other related business processes. PTC has focused efforts on industrial applications where the IT infrastructure is not as modern as the consumer sector. We see PTC's efforts potentially accelerating other areas given the broader touch points across manufacturing. Finally, Autodesk is making early investments to bring the technology to the architecture/construction space in a similar fashion to the example provided previously.

## Trading Systems

Citi and Microsoft collaboration

Microsoft affiliate 8ninths is collaborating with Citi to develop a trading system that uses AR. Microsoft's AR headset Hololens is used to create a virtual trading desk. Gestures and a support rod (pen-shaped instrument) are used to open 3D information boxes and lists to support efficient and intuitive training. We would expect the introduction of the system at a customers' (investors) place of business should improve the quality of information and confidence levels on which investment decisions and the timing of these decisions is based.

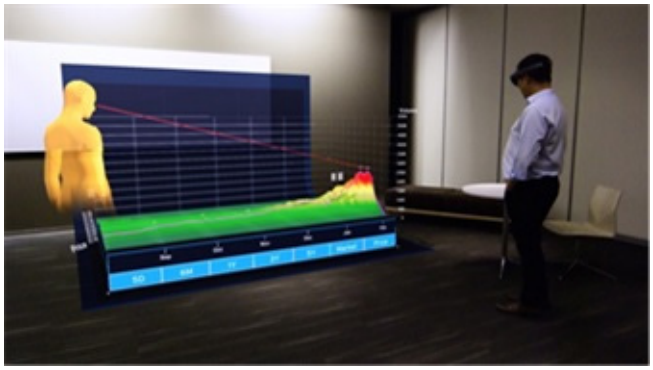
Communication tool with broad scope of application

A trader would not be confined to the trading desk, but could project graphs and maps the size of the room in the AR space, enabling the more intuitive input and analysis of information. This is an area in which the full possibilities of AR can be leveraged, and could be used in innovations other than trading systems as a communication tool with a broad range of applications. In the future, remote location meeting systems will use VR/AR to provide richer information, including people's facial expressions and movement. Further development could achieve the ultimate state of tele-existence, in which there is little difference to actual physical existence in the space.

**Figure 115. 8ninths for Citigroup Trading**

Source: 8ninths

**Figure 116. Large Scale AR in Trading Idea Generation**



Source: 8ninths

## Indian IT Services

**Surendra Goyal, CFA**
India Strategy & India IT Services Analyst

Tata Consultancy Services (TCS) has a global network of Technology Labs, Domain Labs and Academic Alliance Labs. These centers aim to provide an environment for research in leading and cutting-edge technologies like virtual and augmented reality.

1. For instance, TCS has developed a solution around VirtualOffice at its Delhi innovation lab. This aims to provide a virtual rendition of a physical office space. As workspaces become increasingly global, with people from different parts of the world having to connect with each other, solutions like virtual office spaces should see a pick up in coming years.

2. The retail sector is seeing significant demand pickup in multi-channel and omni-channel commerce. An extension of this should ideally lead to a blend of physical and digital retailing, offering a seamless customer experience. In this context, TCS has developed use cases around FitSense for virtual try-on. This solution focuses around facilitating the fitting of garments or accessories over the human body for online shopping using a web/mobile camera.

Figure 117. TCS – Virtual Retail Stores

Source: Company report

3. In the Banking and Financial Services industry, TCS has done work around virtual branch capabilities on self-service kiosks and hand- held devices – facilitating ubiquitous channel integration.

Figure 118. Insurance Through Mixed Reality


Source: Company Reports

4. At its Kolkata Innovation Lab, TCS developed cyber-physical systems, which areIoT platform enhancements that include new sensing platforms, one of them centered on visualization for VR/AR.

Dr. Vishal Sikka, Infosys: "We had this virtual reality equipment from Oculus -- virtual reality gives a tremendous opportunity to reimagine the physical world. Already the virtual reality glasses are close to the precision and resolution of the physical world around us, so it is actually possible to create a replica of walking around in Burberry, Regent Street store or in the Macy's Union Street store and do your purchases without leaving your homes."

Infosys partnered with the robotics team at Carnegie Mellon University to create the "Earth 360 Experience" project an immersive experience featuring satellite images of the world and three explorable use cases around climate change: (1) fires at night; (2) deforestation; and (3) urbanization. In November 2015, delegations from almost 200 countries met in Paris for the United Nations Climate Change Conference, where CEOs from 78 companies including Infosys signed an open letter expressing their solidarity to work with the international community to help deliver practical climate solutions.

Using VR, Wipro's Designit aims to add unprecedented depth to design research. In February, Designit hosted the first ever Immersive Journalism Lab for the Spanish media, teaming up with The App Date and Virtual Natives – inviting 37 journalists from 11 of the biggest media groups to discover, test, and be inspired by the possibilities of VR. This event focused on 3 main areas: (1) empathy generation as viewers can put themselves in someone else's position; (2) new panoramic view to open up new narrative possibilities; and (3) creating unique experiences. The teams produced 10 potential VR narratives and then 2 of those were chosen to create the first VR news pieces in Spain.

HCL Tech has developed two mobile augmented reality solutions:

1. Home improvement application — HCL Tech's AR-based iPhone app enables a seamless shopping experience through simulation and VR features. The use case allows the customer to select a product and get a visual perspective of how it looks – either in a real time or static room image. These solutions aim to cut down on buying cycle time, enhance shopping experience for customers, and improve monetization through quick and easy access to products.

2. Location-based mobile AR application — This helps locate local businesses, shops, and restaurants within a certain radius though a smartphone camera viewer – overlaying corresponding information like address, phone number, websites, reviews, etc.

Mindtree offers a retail virtual store app which leverages advanced surface technologies to create a 3D replica of a shopping mall. This responds to hand gestures and real world objects and aims to make the digital content more engaging and improve customer shopping experience.

Mr. C P Gurnani, Tech Mahindra: "We are also seeing good business opportunities in the digital world, automation and virtual reality."

Tech Mahindra expects its telecom clients to benefit significantly with the rise in VR and AR experience through increased demand for data plans. Persistent Systems has created solutions around virtual medicine to improve consumer-to-provider medical exam experience through integrated medical devices and video conferencing within kiosks.

India is also seeing an active start-up scene with several small and niche companies offering solutions in the VR/AR space. For example, recent media reports highlight that gaming company Empower Labs recently launched an augmented reality mobile game Delta T around time travel. Another media report suggests that another startup Houssup aims to provide superior home decoration and design solutions using VR/AR. Companies like Lenskart and CommonFloor have introduced VR-based shopping experience and property listings. Real estate portal PropTiger.com recently acquired VR/AR start-up 3DPhy which offers 360-degree virtual walk-throughs over multiple devices.

## Advertising Industry

### Will VR/AR Disrupt the Advertising Industry?

**Mark May**
U.S. Internet Analyst

If broadly adopted, VR/AR platforms represent a real threat to traditional mediums of advertising, including current day digital. As the cost of manufacturing VR/AR devices declines, and the price points of these products become more affordable for the mainstream consumer, we envision increased adoption of these technologies over the next few years, and even see some scenarios where these devices become as ubiquitous as the smartphone or personal computer in the not-so-distant future. Ultimately, if VR and AR overcome certain barriers (notably affordability, and for VR, relative lack of mobility vs. smartphones), prove out their use cases, and demonstrate their superiority to traditional technologies (PCs, smartphones, TVs, etc.), we believe there could be a noteworthy migration of time spent to these new platforms, which will force brands, advertisers, and other marketers to significantly adjust their strategies for influencing consumer behavior.

In March of 2014, Facebook acquired Oculus VR Inc., a leading virtual reality technology manufacturer. On the acquisition call with investors, CEO Mark Zuckerberg rationalized the $2 billion-dollar purchase by stating: "The history of our industry is that every 10 or 15 years there's a new major computing platform, whether it's the PC, the Web or now mobile […] and now we're starting to also get

ready for the platforms of tomorrow. To me, by far the most exciting future platform is around vision or modifying what you see to create augmented and immersive experiences. Today's acquisition is a long-term bet on the future of computing. I believe Oculus can be one of the platforms of this future."

In order to expand on Mark Zuckerberg's statement above, in Figure 119 we highlight the shifts of time spent by U.S. adults on media platforms that have taken place over the last four years. Although total time spent on media has increased by only 4%, the shifts within this time spent figure have been dramatic.

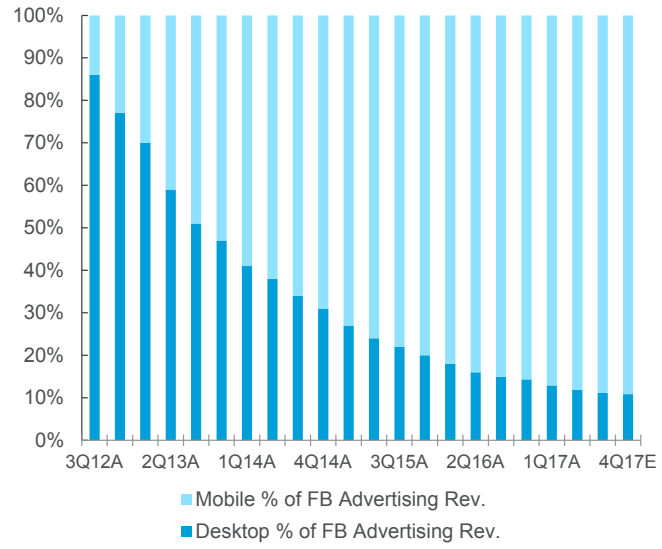
**Figure 119. Average Time Spent per Day with Major Media by U.S. Adults (hr:mins)**

| | Average Time Spent per Day with Major Media by U.S. Adults, 2012 - 2018 (hr:mins) | | | | | | | Percent |
|---|---|---|---|---|---|---|---|---|
| | 2012 | 2013 | 2014 | 2015 | 2016 | 2017 | 2018 | Change |
| **Digital** | **4:10** | **4:48** | **5:09** | **5:28** | **5:43** | **5:53** | **6:01** | 44% |
| **- Mobile (nonvoice)** | **1:28** | **2:15** | **2:37** | **2:53** | **3:06** | **3:15** | **3:23** | 131% |
| ---- Radio | 0:26 | 0:32 | 0:39 | 0:44 | 0:47 | 0:50 | 0:52 | 100% |
| ---- Social networks | 0:09 | 0:18 | 0:23 | 0:26 | 0:29 | 0:32 | 0:34 | 278% |
| ---- Video | 0:09 | 0:17 | 0:22 | 0:26 | 0:29 | 0:31 | 0:34 | 278% |
| ---- Other | 0:44 | 1:08 | 1:14 | 1:16 | 1:20 | 1:22 | 1:24 | 91% |
| **- Desktop/Laptop** | **2:24** | **2:16** | **2:14** | **2:12** | **2:11** | **2:10** | **2:08** | -11% |
| ---- Video | 0:20 | 0:22 | 0:23 | 0:24 | 0:25 | 0:25 | 0:24 | 20% |
| ---- Social networks | 0:22 | 0:17 | 0:16 | 0:15 | 0:14 | 0:13 | 0:13 | -41% |
| ---- Radio | 0:07 | 0:06 | 0:06 | 0:06 | 0:06 | 0:06 | 0:05 | -29% |
| ---- Other | 1:35 | 1:31 | 1:28 | 1:27 | 1:26 | 1:26 | 1:26 | -9% |
| **- Other connected devices** | **0:18** | **0:17** | **0:19** | **0:23** | **0:26** | **0:28** | **0:30** | 67% |
| **TV** | **4:38** | **4:31** | **4:22** | **4:11** | **4:05** | **4:00** | **3:55** | -15% |
| **Radio** | **1:32** | **1:30** | **1:28** | **1:27** | **1:27** | **1:26** | **1:25** | -8% |
| **Print** | **0:40** | **0:35** | **0:32** | **0:30** | **0:28** | **0:27** | **0:26** | -35% |
| ---- Newspapers | 0:24 | 0:20 | 0:18 | 0:17 | 0:16 | 0:15 | 0:15 | -38% |
| ---- Magazines | 0:17 | 0:15 | 0:13 | 0:13 | 0:12 | 0:11 | 0:11 | -35% |
| **Other** | **0:38** | **0:31** | **0:26** | **0:24** | **0:22** | **0:21** | **0:20** | -47% |
| **TOTAL** | **11:39** | **11:55** | **11:57** | **12:00** | **12:05** | **12:07** | **12:08** | 4% |

Source: eMarketer, Citi Research – Percent change represents 2012-2018

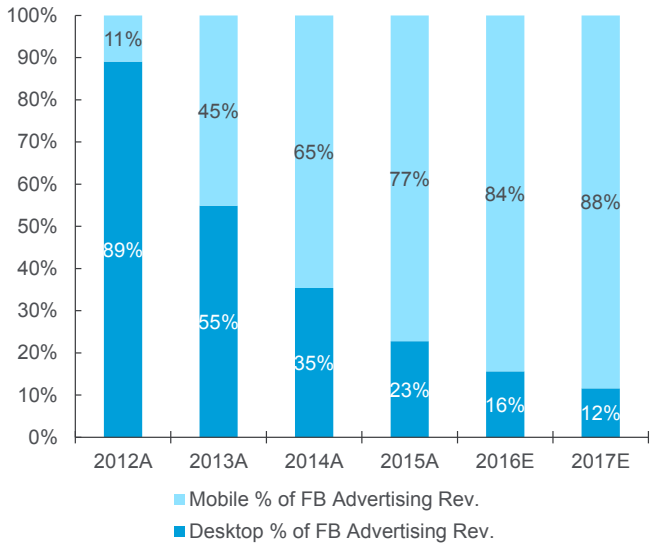
For example, at the end of 2012, the average U.S. consumer spent 40% of media time on TV, 21% on desktop and only 13% on mobile devices. However, given the continuous improvement of mobile technologies, the decreasing price points of smartphones, and the resulting mass adoption of these devices by the U.S. consumer, mobile time has seen its share increase to 26% of total media time, while desktop has declined to 18% and TV to 34%. In 2012, anticipating this shift, Mark Zuckerberg pivoted Facebook to a mobile-centric product, which at the time was considered to be a controversial move. However, given the shift to mobile over the last few years, Facebook has been able to distinguish itself as one of the premier global marketing platforms as a result of taking the steps to identify the next emerging computing platform.

**Figure 120. Quarterly Mobile and Desktop Mix of FB Advertising Revenue**




Source: Citi Research, Company Reports

**Figure 121. Annual Mobile and Desktop Mix of FB Advertising Revenue**




Source: Citi Research, Company Reports

With one of the largest and fastest growing advertising platforms now throwing its weight behind virtual reality in a big way via the Oculus VR acquisition, we believe that there is a growing perception in the advertising industry that VR represents an emerging computing platform approaching mass consumer adoption. If this broad adoption ultimately transpires, the time spent on other platforms, notably desktop and TV, but also mobile, could be significantly impacted, which will also impact the advertising dollars flowing to these channels. As a result, we are already seeing various other companies in our coverage universe developing and/or introducing VR/AR technologies, such as Alphabet, Twitter, and Amazon. Ultimately, we believe that all major digital media platforms should be developing VR/AR products in order to hedge their business models against the potentially disruptive adoption of virtual and augmented reality by the mainstream consumer.

VR is more immersive than TV or PCs

Most importantly, VR is an immersive experience that monopolizes an individual's focus. As a result, we believe VR technologies have the potential to be more disruptive than digital was to TV, and mobile was to desktop, because these earlier devices could be used simultaneously, whereas VR will dominate a consumer's attention while immersed in the experience. For example, as shown in Figure 119, we have seen total time spent on media grow by 4% over the last four years, which incorporates cross-screen usage (e.g. a person could spend ten minutes watching TV while also using his/her smartphone to view social media), resulting in a double-counting of sorts. This cross-screen usage situation enables a monetizable opportunity for both the TV network and the social media platform. However, given its immersive experience, when a consumer uses a VR device, that consumer will be solely focused on the virtual experience, which will result in fewer, yet higher quality, monetizable impressions.

Given this situation, we are already seeing some advertisers take the first steps to readying their advertising strategies for consumer adoption of VR devices. For example, during the World Cup in the summer of 2014, Coca-Cola sponsored a virtual experience that allowed users to explore Maracanã Stadium's locker room and play soccer on the stadium's field. This not only provided a unique and enjoyable Coca-Cola-associated experience for users, but also delivered various branding opportunities within the experience for the company. With users fully immersed in the virtual reality experience, we believe that certain experiences could result in return on investment (ROI) opportunities that far exceed traditional media. Other companies that have experimented with VR include: HBO, The North Face and Marriott Hotels, among others.

VR could be used by consumers looking to try before they buy

In addition to the branding opportunities, we are also seeing companies increasingly use VR to enable users to better explore and understand their products. For example, Lowe's HoloRoom enables customers to envision a home improvement project before lifting a hammer or paint brush by enabling a full 360 degree immersive experience of a renovated project. In addition, Volvo partnered with Google Cardboard to provide a VR experience that allowed individuals to test out the Volvo XC90 prior to its release. Ultimately, we see experiences like these becoming more commonplace, and it will be critical for media platforms to strategically position themselves for this potential advertising environment.

Although most of our comments up to this point have been focused primarily on VR, we also see notable disruptive potential for advertising from augmented reality. In fact, augmented reality most likely represents a more disruptive force to traditional advertising mediums over the near term. For example, we see great potential for AR capabilities that would enable consumers to see prices, wait times, and menus while walking by a restaurant, virtual advertisements on walls (that could better target customers based on known personalized preferences), and features as basic as sponsored images for photos. Given that AR interacts with a 'real' environment, and given its relative ease of use vs. VR, we see AR as being a more realistic advertising medium in the near term.

Ultimately, if VR and AR are able to prove out their use cases, realize an affordable price point, and as a result, achieve broad consumer adoption, we see the potential for disruption of traditional advertising by these emerging platforms. Given recent AR and VR activity in our coverage universe, broad consumer adoption could be a lot closer than previously believed, which could subsequently result in transformative shifts in the global advertising landscape.

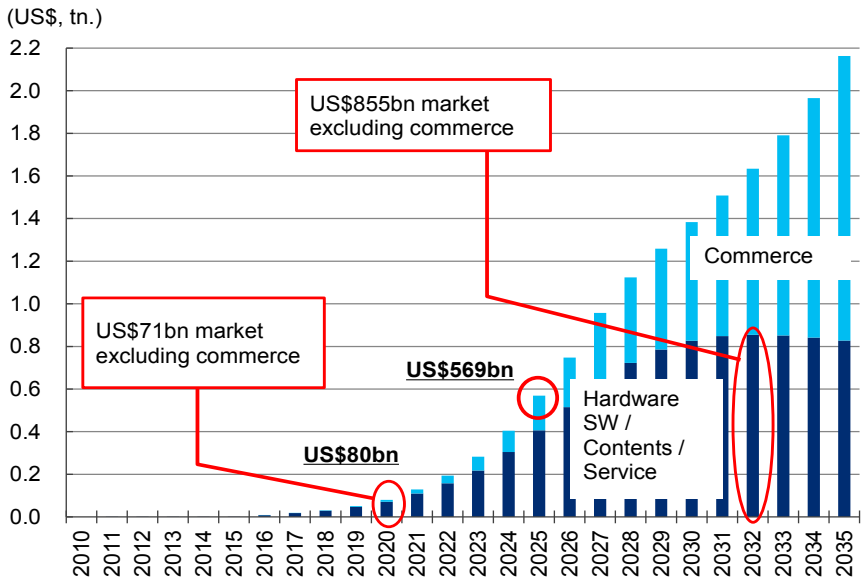
# VR/AR Market Growth

## Potential Size of VR/AR Market is $80 Billion in 2020 and $569 Billion in 2025

We feel the VR/AR market is one with a long tail, and we think it will be used in a wide range of applications in a number of different industries going forward. Taking a big picture view, we think AR has the properties required to substitute for the current smartphone market and that VR has the properties required to substitute for the current game industry. However, we believe there will be significant benefits from the generation of entirely new markets.

VR game applications are the field where we think the obstacles to diffusion are lowest and here we expect 2016, when the game device maker-Sony is slated to launch a goggle-style game terminal, (PS VR), to be the year VR takes off in earnest. We put the total market, including infrastructure like VR/AR headsets, content and services for the devices, and ecommerce that leverages AR, at $80 billion by 2020 and $569 billion by 2025. Even excluding the retail shopping market (e-commerce), where there is little dependence on VR/AR technology, we put the market at about $71 billion by 2020, with the peak in 2032 of $855 billion.

**Figure 122. Estimated Market for VR/AR**




Source: Citi Research

## Headsets to Drive VR/AR Market Growth in the Near Term

Focus on headset market expansion over the next five years

Right now the VR/AR market is in a "chicken or the egg" situation, in which headsets will have a hard time selling if content and services are not beefed up, but there will be little in the way of business opportunities in content and services if the headset sales do not pick up. This is making some companies hesitant to develop products in this area. Appealing hardware as well as contents and software are necessary for the VR/AR market to expand. Widely distributed personnel and elemental technologies (including services, retail, tourism, amusement parks, and sporting events) are a feature of the VR/AR industry. Over the next five years, we forecast hardware, mainly headsets, will by the driver of industry growth. We expect VR headsets to take off first, as companies aim to increase game enjoyment. For there to be explosive growth in VR headsets for consumer applications other than games, we think prices will have to come down to

$300-$400 (average price excluding smartphone VR) over the next two to three years. AR headset technology is more expensive, so we think it will take five to ten years for these to become mainstream in consumer applications. Potential demand volume in commercial applications for VR and AR headsets looks to be lower than that for consumer applications, but we expect steady uptake over the short to medium term.

Headsets are key

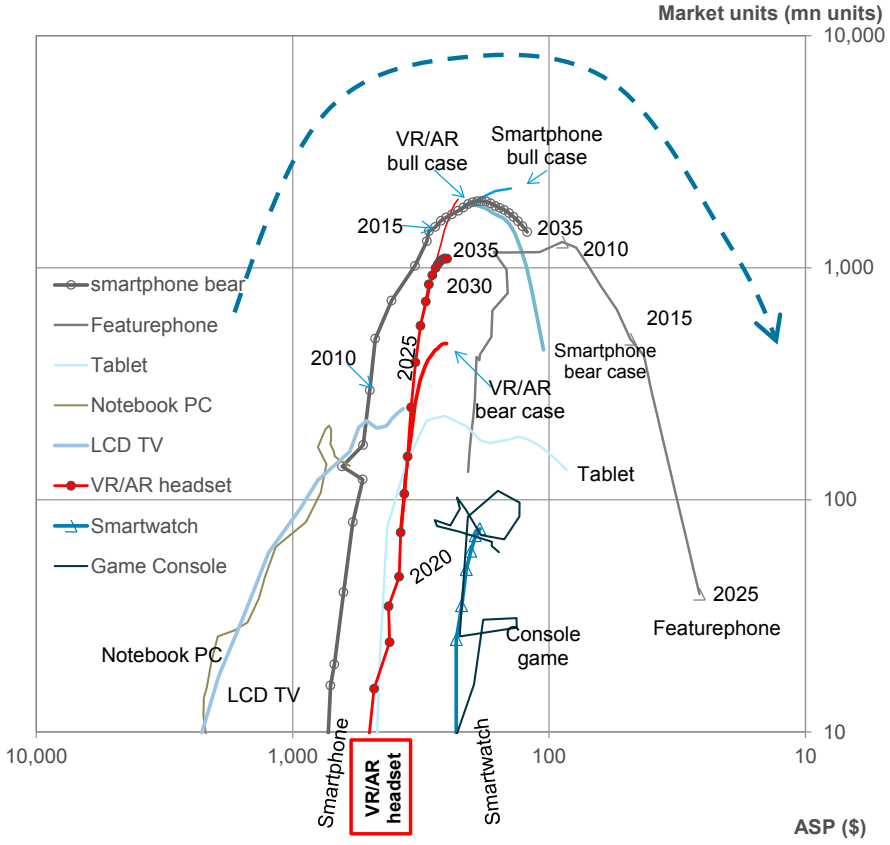
Why do we think hardware (in particular headsets) will be vital for the overall VR/AR market in the short term? The e-commerce market did not take off until PC uptake was sufficient. The market has now hit $1 trillion and has been growing at 10%-20% annually. Within e-commerce is the growing field of mobile commerce using mobile phones. This market has been expanding in line with the uptake of smartphones, with little difference in timing between increases in device usage and expansion for commerce. The mobile commerce market is currently around $300 billion and has been expanding at a rate of 30%-50% annually. This suggests that increasing popularity of VR/AR headsets is likely to mean rapid expansion for AR commerce at roughly the same time. In our view, the key to AR commerce expansion is headset expansion.

In addition, in terms of investment, efforts in VR/AR are not exactly new in commerce. Additional investment is necessary, but we think it will be smaller than that needed to launch the first online shop, and visibility on the future of the business is better. The psychological hurdle to spending on VR/AR content and services seems low, and we think it will expand as headset uptake does.

Headset expansion to look similar to smartphone expansion

We also think market expansion for VR/AR headsets is likely to look like that for smartphones in terms of speed and scale. We anticipate similarities in terms of application and costs for electronic components and semiconductors.

**Figure 123. Prices and Volumes for Major Consumer Electronics Products**




Source: Citi Research

## VR to Take Off First, Followed by AR and Commerce

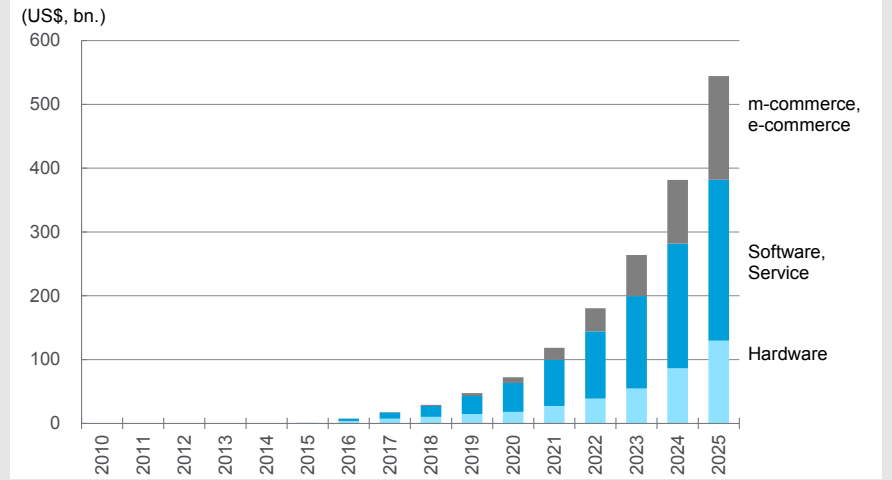
Massive markets for both hardware and software

We project long-term growth in the VR/AR market to $569 billion in 2025, and further growth thereafter. The market is presently set to ramp up from 2016. For the 10 years through 2025, we forecast a CAGR of 93%.

The market will begin the ramp up with the simultaneous launch of both VR and AR headsets, but we think that VR will be the main driver over around 5 years. We forecast a market for hardware (headsets) of $9.6 billion in 2025, assuming sales of 39 million units in 2025 and that the average unit price declines from $289 in 2016 to $248 in 2025.

We think the primary VR content will initially be game software, but that the market will then expand to include concerts, zoos, and theme parks before broadening further to encompass sports match, movies, TV programs, and music. We think the market will remain small at just $3.1 billion in 2016, but we forecast growth to $40.0 billion in 2020 and $138.7 billion in 2025. AR is likely to be trialed in areas with special needs, such as design work, construction sites and warehouses (material handling), and medicine from around 2020 and gradually spread from there. Thereafter, we expect miniaturization and reductions in the power consumption for AR devices (glasses, goggles and headsets) worn on the eyes and head to promote explosive market uptake by consumers.

**Figure 124. Breakdown of VR/AR Market into Hardware, Software & Services, and Commerce**




Source: Citi Research

## VR Headset Market to Become 39 Million Units by 2025

VR headset market size

The earliest VR headsets appeared on the market around 2013 in a venture-like trial, but we expect the genuine ramp up of the market to start this year, in 2016. This is when products by Oculus, which was acquired by Facebook, and Sony are to be launched.

Given the cost of the display, sensors, and other materials, and the scale of volume production (small initially), we put the average unit price at $289 in 2016. Other than the Samsung Gear VR, which uses the display, sensors and other key devices from smartphones and is priced at $99, we expect other products to be in the $400–$800 range.

We put the market size at 14 million units in 2017, 30 million around 2020 and 40 million around 2025. We think long-term equilibrium will be 40 million annually, and that the unit price will ultimately fall to less than $200.

VR games to develop first…

We think the game industry will be able to develop the market first and most reliably. We expect this market to grow to $16.8 billion in 2020 and $65 billion in 2025. In 2020, we expect game title disc purchases, downloads, and streaming to account for 34% of the overall VR market.

The nature of the graphics design for the first-person shooter games that have enjoyed sustained popularity in the video game market means that the gamer moves the character on the screen in the same way as moving his or her own body. As this design is a good match for VR, we think first-person shooter games will be very easy to convert to VR.

Accordingly, we think that around half of the titles for game consoles will be converted to VR by 2025. Over the long term, the vast bulk of games are likely to be converted to VR, which is likely to become the standard for home games.

…entertainment, commercial applications, tele-existence will follow.

We think VR will spread to theme parks, sporting events, and music concerts. For activities that need to be in real time, such as watching sports and live music, technological advances and reductions in telecom costs will be necessary. However, we think that the fastest growth in this market will center on sports and the like, so we assume a big market in this area. Overall, we forecast a market of $11.5 billion in 2020 and $60 billion in the longer term. However, we think there are many potential industrial applications, and if technological progress accelerates, this market could be many times larger than currently thought.

We think there is considerable potential for growth in commercial applications if technological advances improve quality and reduce initial costs. When we wonder about the atmosphere before booking a restaurant reservation, want to know how quiet a hotel room is before we book, or want to check if an airline seat will have sufficient leg room, we are currently forced to make a passive decision based on limited information on websites. If the cost were feasible, the company providing the service could replace the “virtual tour” on its website with genuine VR. In the long term, we think that VR is a leading candidate for conferencing systems in commercial uses.

Tele-existence is the ultimate incarnation of VR. Tele-existence involves identifying (seeing) objects and people in a VR worlds as well as being able to touch them, speak to them, and mutually interact with them. It is a VR world in which one can talk and walk with people and touch objects to confirm their texture. It would require the user to wear not only a headset, but a range of sensors on their body. This is a field for the long term, but even now there is much active development underway, so it is by no means a dream.

We put the combined market for entertainment, commercial applications and tele-existence at some $11.5 billion around 2020. However, this is based on conservative assumptions for uncertain technological elements and business models, so the potential market is much larger.

Motion video (VR movies, TV, music videos)

While 3D flat panel TVs for the home did not prove popular, watching 3D movies at the cinema has now become an established form of entertainment worldwide. As it is essentially an extension of 3D, we think that the movie-watching experience is the next easiest area for the incorporation of VR after games. We also expect the production of some TV programs and music videos using VR.

In the movie, TV, and music markets we expect a partial fusion with what are currently seen as secondary retail markets in the form of DVDs, VOD, and streaming. We think a business model could emerge under which movies are distributed to consumer PCs over the Internet on the day of the premiere so that they can be watched with the same realistic, immersive experience as watching it in a cinema using a VR device. The shift in the product distribution structure from cinemas to the consumer channel could well cause a major change in the industry itself, and as many uncertainties remain, we factor in only the shift in the market in this analysis.

We think the VR market related to movies, TV, music videos, DVDs VOD, and streaming will start to grow strongly around 2017. We put market size at $2.3 billion in 2017, $11.4 billion in 2020 and $39.5 billion in 2025.

## AR Headset to Become Billion-Unit Market

AR device market size

We expect the market for AR headsets to be comparable to that for smartphones. Ultimately, some consumers will do away with smartphones and use AR headsets for calls and data transmission. We currently envisage AR headsets replacing smartphones in 2025–2030. Through 2025, however, we position AR headsets as a consumer device that will generate net growth in the same way as VR headsets. In the long term, we expect the extent of smartphone market substitution by AR to rise from nearly 0% in 2025 to 48% in 2035.

AR headsets require specialized displays, so we expect unit prices to be relatively high. However, as with smartphones, they will serve multiple purposes, so we think volume production will bring prices down in the long term. Unlike VR, the effectiveness of AR will decline markedly once hardware quality falls below a certain standard, so we see less potential for growth in low-end products than for VR. In around 20 years' time, we expect low-end users to continue to use low-end smartphones and midrange and top end users to shift to AR headsets.

We forecast the AR headset market at $9.1 billion in 2020 and $120.2 billion in 2025. Over this period, we expect the smartphone market to grow from 2.2 billion units to 2.4billion.

AR commerce (shopping, advertising)

Under our current model the biggest market segment is commerce. We forecast that the AR commerce market will grow to a massive $163 billion by 2025. But this would still be not more than 5.8% of the overall e-commerce market, which we put at $2.8 trillion in 2025. By 2035, we project growth in AR commerce to more than $1.3 trillion, which would make it a major channel in the e-commerce market with a weighting of around 28%.

Our forecast for the size of the AR estimate is based on the assumption that AR headsets are used for five years (there is a five-year replacement cycle) and on an assumption for an average annual amount spent per unit of the installed base.

AR voice calls, video calls, email, SNS

AR headsets display CG without completely blocking the user's field of view, so they could be used to make telephone calls and post entries on SNSs. This does not necessarily involve using functions unique to AR, but we think it is likely to be more convenient than using a smartphone, so we expect AR headsets to replace smartphones in some cases. We estimate this part of the market for conventional communication services at $50-$200 billion.

AR as work tool (writing, data handling, graphs/spread sheets, electronic conferencing, data base use)

We think the use of AR could also spread among companies as a work tool. The work we currently do on LCD monitors could very well look different in the future, perhaps through the use of CG. Through the use of AR, it could most likely be possible to display 20 years' of corporate results horizontally in an Excel earnings model. In meetings and presentations, BYOD may well mean that each participant can connect their own AR headset to the internal network to view notes on a laptop PC that would currently be displayed using a projector and screen. We conservatively estimate the market at $20 billion–$30 billion in 10 years' time, but we see ample potential for growth.

**Figure 125. VR/AR Market Forecasts (US$bn)**

| | CY 13 | CY 14 | CY 15 | CY 16 | CY 17 | CY 18 | CY 19 | CY 20 | CY 21 | CY 22 | CY 23 | CY 24 | CY 25 | | CAGR 15->20 | CAGR 20->25 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| VR Hardware | 0 | 0 | 0 | 2 | 4 | 6 | 8 | 9 | 10 | 10 | 10 | 10 | 10 | | 83% | 2% |
| VR Game industry | 0 | 0 | 0 | 2 | 5 | 7 | 11 | 17 | 27 | 36 | 47 | 58 | 65 | | 80% | 31% |
| VR Motion video | 0 | 0 | 0 | 1 | 2 | 4 | 7 | 11 | 17 | 22 | 28 | 34 | 39 | | 107% | 28% |
| VR Entertainment | 0 | 0 | 0 | 1 | 2 | 4 | 6 | 12 | 15 | 20 | 26 | 31 | 34 | | 141% | 24% |
| AR Hardware | 0 | 0 | 0 | 2 | 3 | 4 | 7 | 9 | 18 | 29 | 45 | 77 | 120 | | 51% | 68% |
| AR Commerce | 0 | 0 | 0 | 0 | 1 | 2 | 4 | 9 | 19 | 36 | 64 | 100 | 163 | | 191% | 78% |
| AR Communication | 0 | 0 | 0 | 0 | 1 | 2 | 5 | 9 | 17 | 31 | 50 | 76 | 112 | | NA | 66% |
| AR Commercial/Enterprise | 0 | 0 | 0 | 1 | 1 | 2 | 3 | 4 | 6 | 9 | 13 | 19 | 26 | | 74% | 43% |
| **Total VR/AR** | **0** | **0** | **1** | **8** | **18** | **31** | **51** | **80** | **128** | **194** | **282** | **404** | **569** | | **148%** | **48%** |
| Hardware | 0 | 0 | 0 | 4 | 7 | 10 | 15 | 18 | 27 | 39 | 55 | 86 | 130 | | 110% | 49% |
| Software, Service, Contents | 0 | 0 | 0 | 4 | 10 | 19 | 32 | 53 | 82 | 119 | 163 | 218 | 276 | | 164% | 39% |
| Commerce | 0 | 0 | 0 | 0 | 1 | 2 | 4 | 9 | 19 | 36 | 64 | 100 | 163 | | 191% | 78% |

Source: Citi Research

## AR to Eat into Smartphone Market

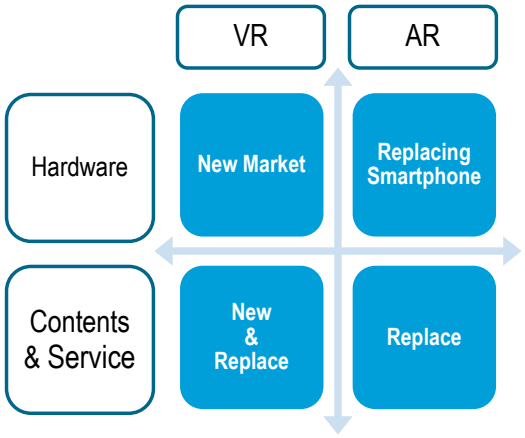
Net gains or cannibalization?

When wearing a VR device, the user is typically restricted to using it in a single location. This represents a new way for people to use a device. As such, VR devices are new types of products that do not overlap with established consumer electronics products in terms of hardware. That is, VR devices can be considered as a genuinely new industry capable of driving net growth in the consumer electronic equipment market. Conversely, VR content will both create new markets and replace existing ones. VR allows a user to travel to far-away places previously unreachable or to watch sporting events they are unable to attend, thus creating new markets. At the same time, VR in movies and games would likely be more disruptive to existing content. In other words, if established movie theaters and game software add VR compatibility, it is possible that conventional movies and games would no longer find purchase among consumers.

Meanwhile, AR differs from VR in another respect. Consumers could use AR in areas like mobile commerce, email, calling/texting, and in mobile meeting tools at work. AR could also be used for mobile advertising, as on smartphones. In other words, the pattern of use of AR will resemble that of smartphones. For this reason, we think AR will start to erode the smartphone market on both the hardware and software sides.

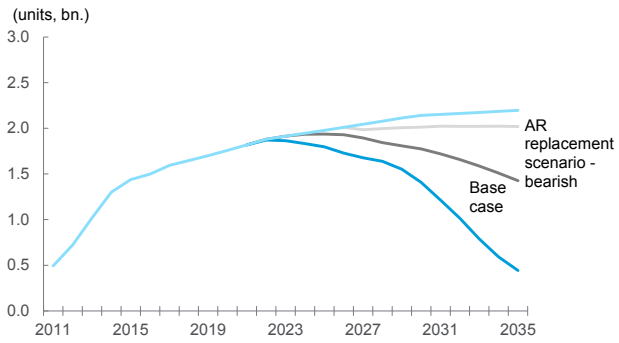
In our current market model, in working out the size of the hardware market for AR headsets we assume that the majority of growth in the AR headset market from 2025 onward will be achieved at the expense of the smartphone market. The 2025 timing is based on anticipated progress in AR headset technology; however, the shift could happen earlier if improvement in the quality of transparent displays or the development of miniature computers gathers pace.

**Figure 126. VR is Mostly New Market While AR is Smartphone Replacement**



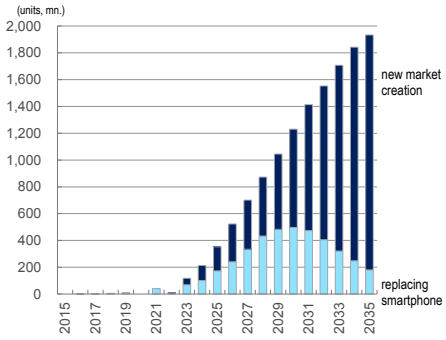

Source: Citi Research

**Figure 127. Smartphone Market Trends Should AR Headsets Eat into Demand**



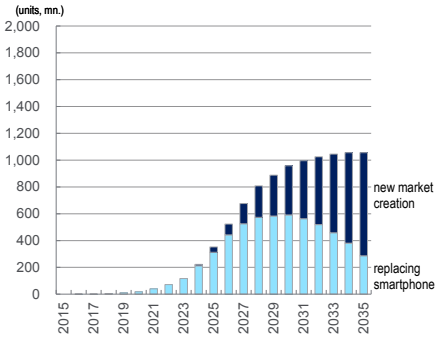

Source: Citi Research

**Figure 128. AR Headsets to Replace Smartphones: bull case**



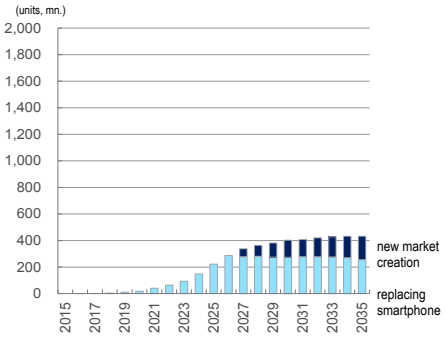

Source: Citi Research

**Figure 129. AR Headsets to Replace Smartphones : base case**




Source: Citi Research

**Figure 130. AR Headsets to Replace Smartphones : bear case**




Source: Citi Research

VR/AR can still be a new growth driver for the consumer electronic equipment market

Even though we think AR headsets will erode some of the smartphone market, we still think VR and AR are the keys to the resumption of growth in the consumer electronic equipment market. In our simulation we expect VR/AR headsets to play a driving role in the digital appliance industry between 2020 and 2025.

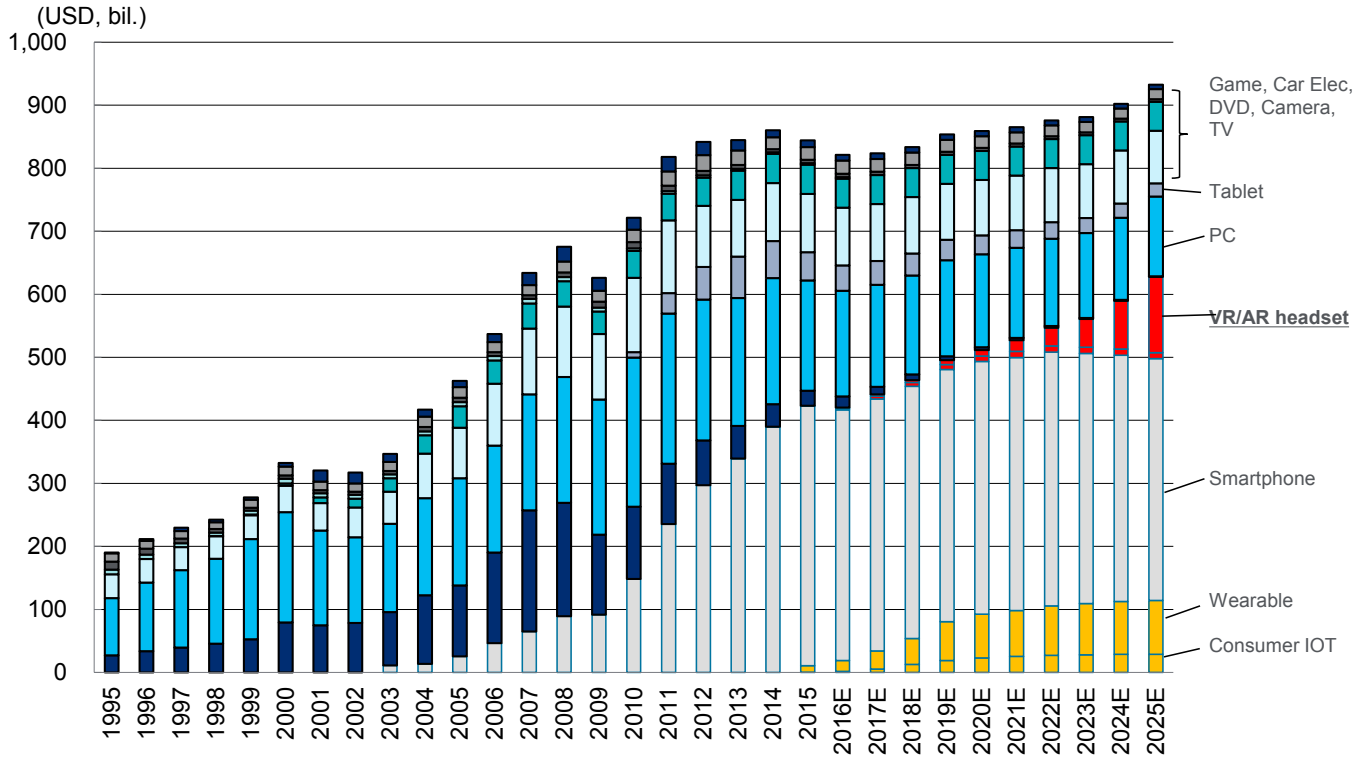
We do not expect much positive news for the consumer appliance market in 2016. We see a struggling smartphone market coupled with a headwind from PC market contraction. There is also substantial concern about negative growth for products like conventional satellite navigation systems, DVD players, and TVs. Wristwatch-style wearable devices and wristband-type wearables are starting to gain traction, but volumes of around 30 million units for the largest player on the market is still some way short of the hundreds-of-million-unit scale of the smartphone, PC, and TV markets. VR/AR will not offer direct support to the industry as a whole either. We therefore expect the stagnation in the hardware industry to deepen.

Meanwhile, economic activity using digital appliances is on the rise. This is because the amount of content consumed via digital appliances is growing while e-commerce (including AR commerce) and use in the enterprise domain is still expanding. This shifting of added value from hardware to software is likely to continue. In these conditions, hardware manufacturers are being called upon to move beyond the so-called "selling boxes" model of simply producing and selling hardware to a model that includes the selling of content and software, thus allowing revenue to be generated whenever the hardware is used (sometimes called a platform business).

The range of economic activity that can be accomplished using VR/AR hardware is extremely large. This makes it difficult for hardware manufacturers to be able to cover all the necessary content, services, and applications. Similarly, on the commerce side it is unlikely that shopping tied to specific hardware will become popular.

These conditions will make it difficult for hardware firms to generate synergies. At the same time, we think companies capable of running diverse non-hardware businesses will be able to find a competitive edge through their business models. It could be argued that one reason that Microsoft, Google, and Facebook are pursuing VR/AR so aggressively is because they have plenty of management resources and expect earnings opportunities to grow beyond the hardware itself. Sony's portfolio of content including games, movies, and music will allow the company to build a platform business to compete against Google. We think these companies will be in the vanguard when these kinds of businesses are farther along in terms of development.

**Figure 131. Trends for Major Consumer Electronics Products**




Note: We use a simplified formula for estimating the markets for game devices, auto electronics, DVDs, cameras, and feature phones in 2018 and beyond.
Source: Citi Research.

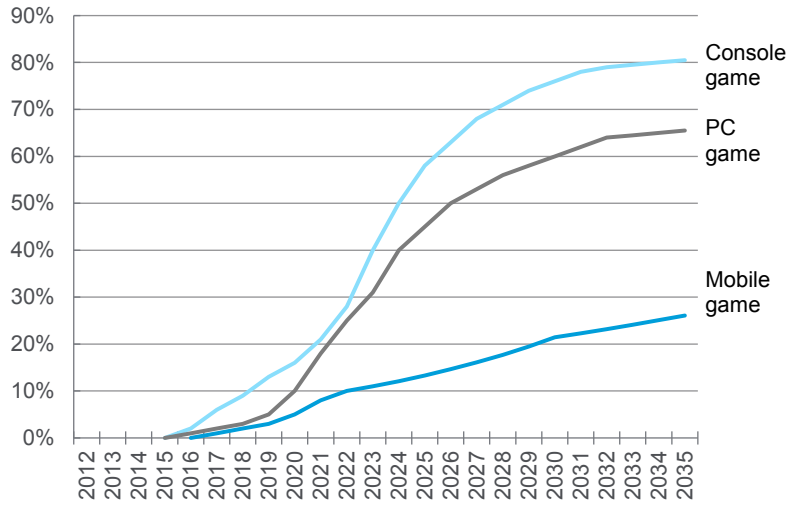
## Conversion of Media Content to VR

VR games

The game market can be divided into PC games, console games (as typified by Xbox and PlayStation), and smartphone and other mobile games. We think the segments that will see the soonest growth in VR content (i.e., game titles) will be PC and console games. Many mobile games do not require VR, and given the processing power of smartphones, VR would not be feasible immediately, but there are possibilities over a longer time frame more than 10 years' into the future.

We think that the percentage of VR games will rise more quickly for console games than PC games. The same number of VR titles may emerge for PC games as for console games, but the PC game market is larger, so in percentage terms, conventional games are likely to remain the mainstream for longer. Many PC are multiplayer and massively multiplayer online games, and it will not be easy to use VR headsets given their performance limitations in the near term, so we expect the ramp up of VR to be more rapid for console games.

**Figure 132. VR Ratio for Major Game Types**

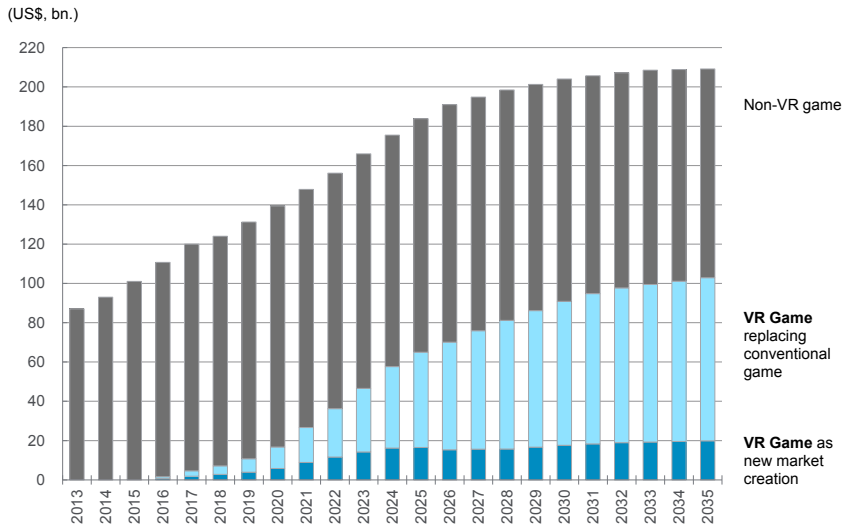



Source: Citi Research

We estimate that game software market at $110.7 billion in 2016, with the breakdown $35.5 billion for PC games, $25.6 billion for console games, $34 billion for mobile games and $14.9 billion for other. We forecast CAGRs of 6.17% for this market in 2015-2025 and 1.3% in 2025–2035. This would put the 2025 market at $183.8 billion.

We think the market will center on console games through 2020 and that PC games will begin to contribute in 2020–2025, with mobile VR games emerging after that. So we project growth in VR games from $16.8 billion in 2020 to $65 billion in 2025 and $102.9 billion in 2035. This would represent 12%, 35% and 49%, respectively, of the overall game market. We expect VR titles to replace 16% of all console games by 2020 and 45% of all PC games by 2025. In reverse, we forecast that games will account for 34% of the overall VR market by 2020 (disc purchases, downloads and streaming).

**Figure 133. Game Content Market (VR, Non-VR)**



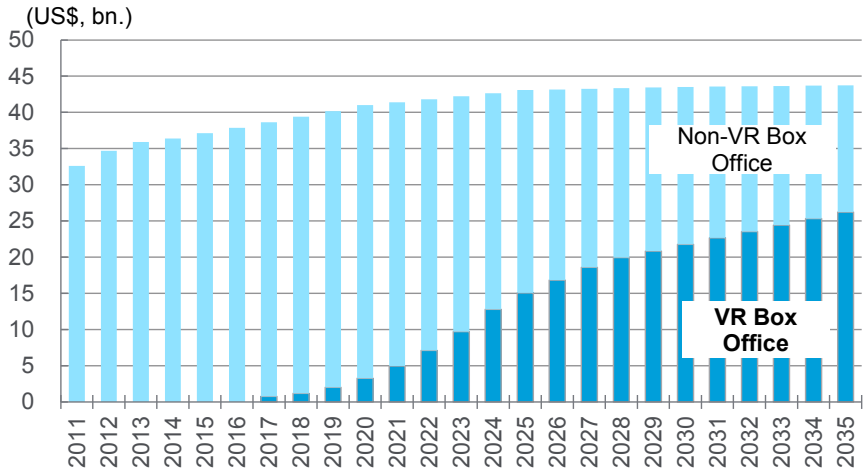

Source: Company data, IDC, Gartner, VZ Charts, Newzoo, Citi Research

VR movies, DVD/VOD/streaming

We expect VR to drive big changes in cinema. Not only will the form in which movies are watched likely change, but cinema content itself is likely to change to suit VR headsets. While the impact that the latter change will have on the movie market is unknown, in this analysis simply assume that movies become VR compatible at the same rate as market uptake of VR headsets increases. We also expect movie theaters to provide customers' with VR headsets in the same way as they do 3D glasses.

We estimate the movie screening market at $35 billion–$40 billion, and expect the number of VR movies to begin to grow strongly around 2019. Rather than market uptake of VR headsets, we think the key factor will be a reduction in the price of headsets to the point that it is commercially viable for movie theaters to provide them to customers. We assume that the percentage of movies that are VR compatible is 8% in 2020 and 35% in 2025.

**Figure 134. Scenario for Shift in Movies to VR**

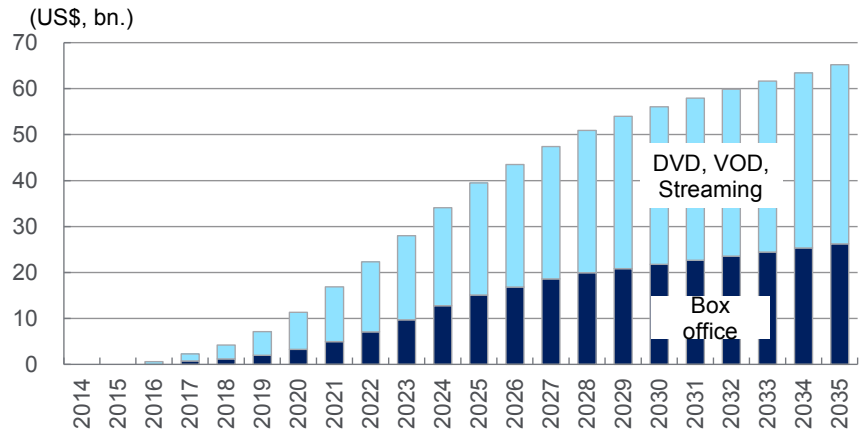



Source: Citi Research

We also expect uptake of VR for secondary uses of movies after they have been released, such as DVDs. Other than movies screened in cinemas, we think other VR content will be produced for distribution via VOD channels, and that VR will be adopted more quickly in the secondary use market than for movie screenings.

We project the movie-related VR market at $11.4 billion in 2020 and $39.5 billion in 2025. While we expect TV content, music videos, and so on to become VR compatible in the same way as movie content, our market projections factor in only DVDs and other secondary uses (we do not factor in TV broadcasts and public screenings.).

**Figure 135. VR Movie and DVD Market**




Source: Citi Research

Sporting facilities are large and are extremely well-suited to VR/AR.

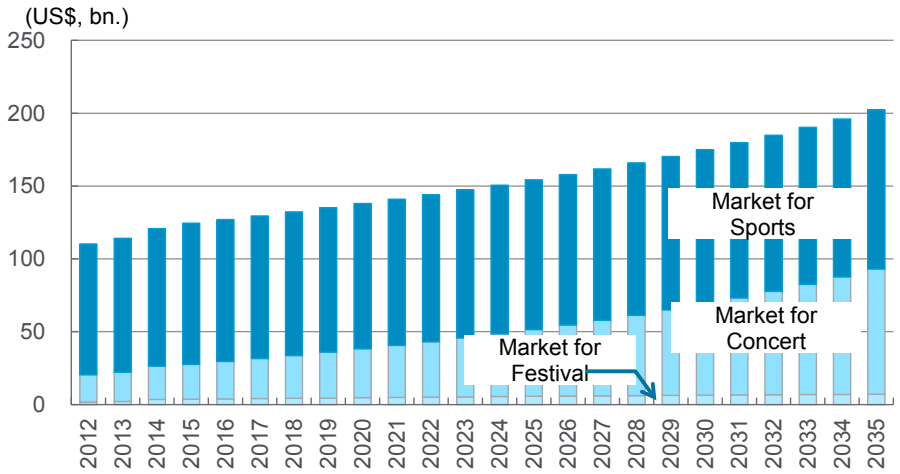
Professional sports boast global viewership via people attending events, people watching on TV, and people watching in public spaces. A number of camera techniques and information services already exist that make the experience more realistic. This market is extremely well-suited to VR and we think VR/AR will grow significantly in this space, with the pace of growth limited to headset diffusion, however.

Concerts and festivals one major market

We think that VR is also highly compatible with music concerts. Once the installed base of VR headsets reaches to critical mass, we expect the market to begin to ramp up around 2019, and ultimately grow into a VR market in excess of $30 billion.

Our estimate on the world concert market was at $24.6 billion in 2015and the festival market at $3.6 billion, and forecasts a growth rate of around 5% in the concert market in both developed and developing nations..

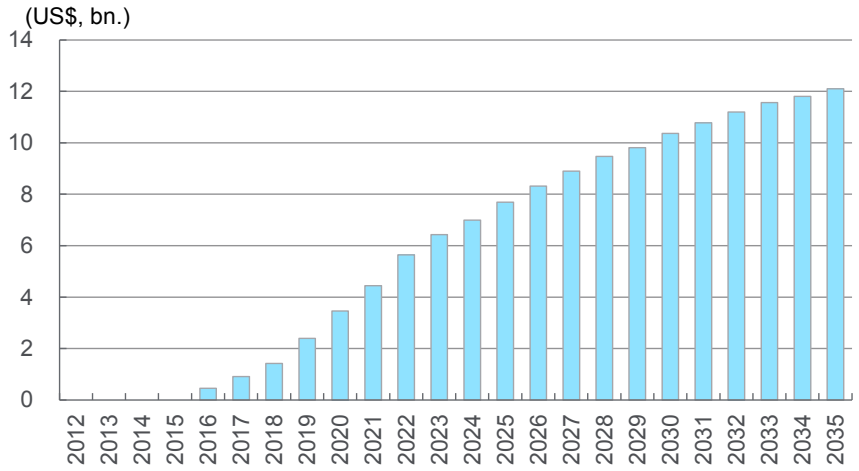
**Figure 136. Global Sports, Concert and Festival Market**




Source: Citi Research

We forecast growth in the world sports, concert and festival VR market to $11.5 billion in 2020 and $32 billion in 2025. While much of the VR sports, concert, and festival market will come from the substitution of existing markets, we also expect the creation of a reasonably large new market. This essentially means the production of events such as concerts specifically for VR. We project this market at $8.5 billion in 2020 and $22.7 billion in 2025, as part of a total market of $11.5 billion and $32 billion.

**Figure 137. VR Sports, Concert and Festival Market Trends**




Source: Citi Research

Other entertainment, commercial applications, tele-existence

VR markets for which we did not do a detailed analysis but simply factored in tentative assumptions are commercial applications such as conferences and service areas in which VR looks like it could be useful, such as restaurant and hotel bookings. We assume that these markets total $2.2 billion in 2025.

## AR Commerce Potentially a Big Part of Online Retail Market

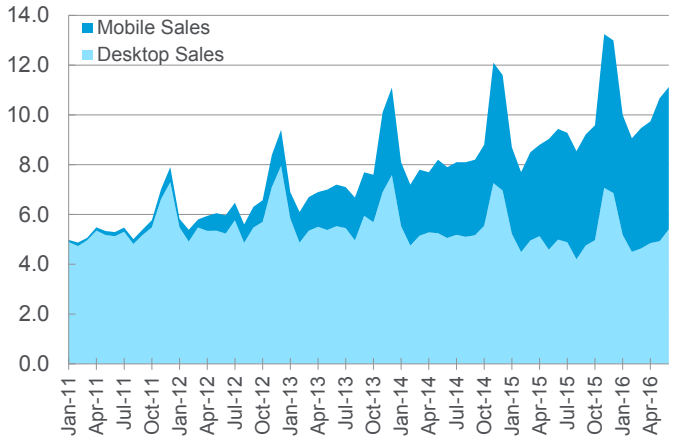
**Dan Fox Homan**
European General Retail & E-Commerce Analyst

Online retail is continuing to grow at a rapid rate and will contribute around 8% of the total global retail market in 2016, according to Euromonitor, with annual sales of $1.2trillion. We expect this sales figure to double over the next 5 years. Mobile commerce, or m-commerce, is already over one-third of the global online retail market, having grown at +70% annually since 2010.

Taking more developed online markets, such as the UK, shows that mobile is already 50% of online retail sales and has generated all of the growth of this sector since 2012.

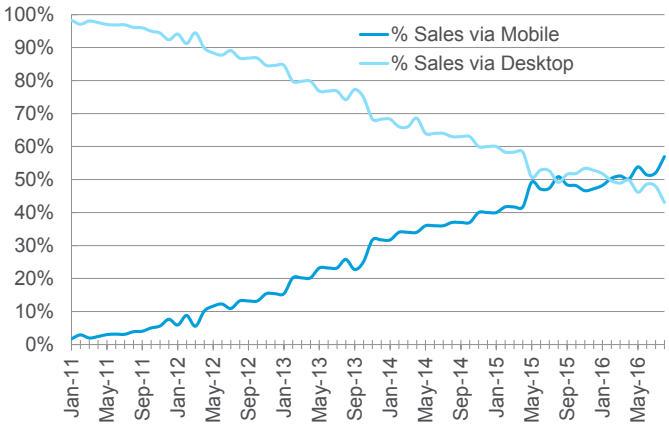
Mobile devices were readily available and used well before m-commerce really started to grow. We think there were three major developments that drove the growth of m-commerce:

**Figure 138. UK — Monthly Online Sales by Device, £bns**




Source: Citi Research

**Figure 139. UK— Split of Online Sales by Device**




Source: Citi Research

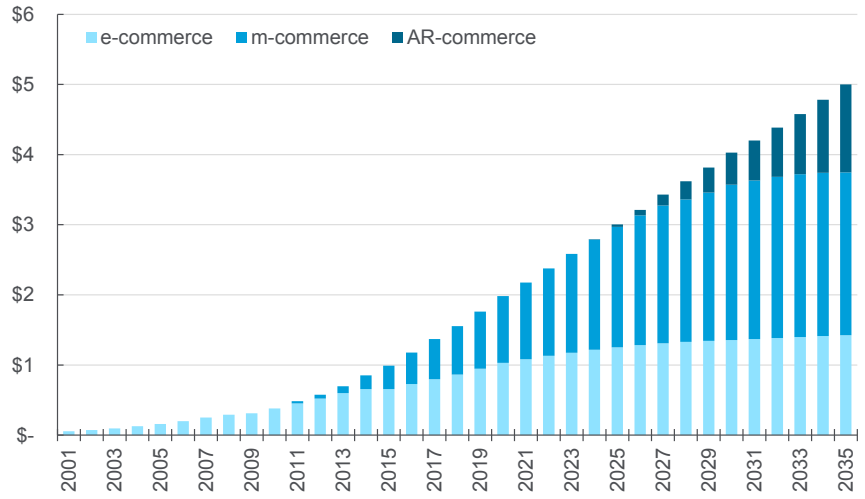
- **Increasing size of phone screens** has allowed retailers to correctly display and merchandise products on a mobile device.
- **Availability of mobile data** has allowed consumers to shop for products at any time of day, without needing to be connected to WiFi networks to receive large amounts of data.
- **Payment systems** have given the ability to pay over mobile devices using a range of payment methods allowed transactions to be completed on the device.

AR commerce consumer behavior is likely to be similar to current mobile commerce. AR commerce will enable a range of consumption behavior using graphics displayed on the headset. We expect users to use AR headsets in the same way that they current use smartphones to make purchases, enjoy content, and make bookings for a variety of services. This AR commerce is not intended to be used when sitting on a chair at home, but rather when out and moving about and taking a break. In this sense, usage could be like that of smartphones.

## How Fast Will AR-commerce Market Grow?

In envisaging a shift to AR-commerce, the main determinant of growth will likely be the uptake and use of the devices, particularly with regards to replacement of smartphones. Therefore, the transition to AR-commerce from m-commerce as a transactional platform could be significantly faster or slower than the growth of mobile, dependent on the speed of uptake of the technology.

**Figure 140. Global Trends in AR Commerce, Mobile Commerce, E-Commerce**




Source: Euromonitor, Citi Research.

Using Citi's estimates that AR-headsets will start to cannibalize mobile sales in 2024 and that annual smartphone unit sales will peak in 2025, we forecast CAGRs for the AR-commerce market of+66% in 2025–2030 and +22% in 2030–2035.

## Which Companies Benefit?

Perhaps the more interesting question is how this affects online retail growth in total. Whether the transactional platform is desktop, mobile, or an AR-device, the underlying logistics and economics of delivering the product to the consumer won't be affected. There could, however, be an impact on the propensity to use online retail as a platform if goods could be envisaged in-situ using AR technology.

AR has many potential uses for retailers

This could be in the form of seeing how the clothes look in the mirror, how furniture will fit into a room, and what make-up will match best against skin tone. These examples of consumer consideration are one of the most cited reasons for continued use of traditional shopping locations. If VR/AR was able to help overcome these barriers, then it may further speed up the transition from store-based to online retail.

The final question to consider is which companies can monetize this potential shift in spending patterns? We would argue that much like m-commerce, it benefits those specialist online retailers that have the ability to invest in forward- looking growth projects and marks another shift in spending patterns those traditional store-based retailers are going to lose out from.

Any company that can provide robust VR/AR technologies that allow retailers to encourage consumers to buy online could become important support industries for the retail sector.

The important point would be that this does not create an additional industry, but rather it cannibalizes an existing retail industry. The total amount of retail spending would be unlikely to change. In this sense, the growth of AR-commerce is not real growth, but a shift in consumer spending patterns on which definitive winners and losers cannot yet be predicted.

### Is There a Nearer Term Opportunity?

AR could also help retailers fulfill customer orders more efficiently

Retailers are increasingly referring to AR technology with regards distribution centers. The growth of online retail has driven massive growth in distribution centers that require humans to pick the product from shelves using some kind of tablet or wrist mounted device to find the correct location. The use of AR headsets would free up hands of the pickers and would also enable them to auto-recognize the product, thereby reducing error rates.

Given the rapid pace of change of online retail and the substantial costs of full automation, the use of AR headsets may become more prevalent in the future as retailers look to maximize efficiencies of distribution centers.

## Payments, Processors & IT Services

**Ashwin Shirvaikar, CFA**
U.S. Payments, Processors & IT Services Analyst

The significant potential of VR/AR technology has been well documented, with 2016 generally designated as a break-out year for the technology in terms of early adopter awareness and also early use-cases that have been well-documented throughout this report. Indeed, the creation of new markets for VR/AR commerce and software, service, and content, are collectively estimated to be worth ~$420 billion by 2025, according to Citi estimates.

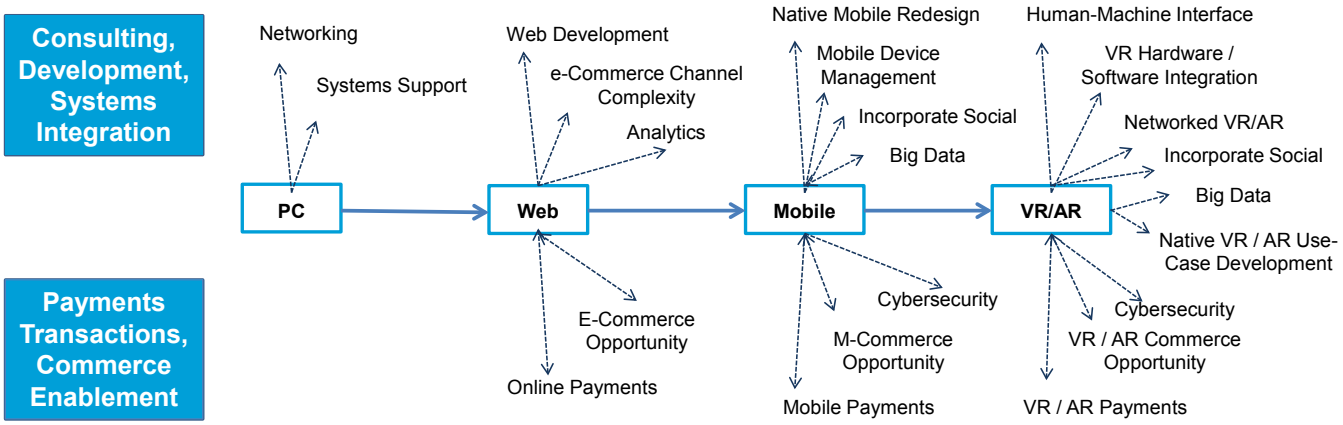
The Services industry – this includes IT Services such as Consulting, Development and Systems Integration and Payments Services such as the Processing of the payments transaction and the enablement of commerce – is one of the building blocks in this evolution. This is a path we have followed in previous instances of disruptive channel shifts. Figure 141 illustrates this and makes the following two points:

1. As we progressed from the PC to the web to mobile to (now) VR/AR over the past three decades, there was a growing demand – more for each successive technology generation – for the relevant IT Services talent for a range of tasks. Some examples are shown below in Figure 141, though this is not a fully comprehensive list.

2. The corresponding Payments Services industry developed later – with early developments only 15-20 years old. But these were often symbiotic applications. In other words, because it was possible to make a market and monetize, it actually resulted in incremental investment in the channel. For example, successful e-commerce and m-commerce growth both came from and contributed to the growth of the online and mobile channels.

We believe the above points should be even truer for AR / VR technology.

Figure 141. With VR/AR, the Services Industry Can Continue Its Track Record of Increasingly Symbiotic "New Channel" Growth




Source: PayPal, United States Patent and Trademark Office

## Payments & Processors

Payment processors and networks provide the rules and mechanisms necessary to transact in VR/AR environments, similar how these players enable e-commerce and m-commerce today. However, there is at least one critical difference. Given the immersive nature of the VR experience and the integrated nature of the AR experience, the payments experience must be seamless and digital-only. In some ways, we look at VR-based payments as being a classic end-result of our inevitable progression towards an "Experience Economy", a concept we broached in our 2015 report Digital Money: A Pathway to an Experience Economy. Of course, the way one transacts will be different – there is no card swipe or card tap possible in the middle of a "Pokémon Go" chase, for example. Speed is important – hopefully measured in milliseconds and not several seconds like the current U.S. EMV experience. For this, payments credentials must be securely stored and accessed – and recent developments in terms of cloud-based tokenization are appropriate. Using biometrics for user identification is likely not an issue.

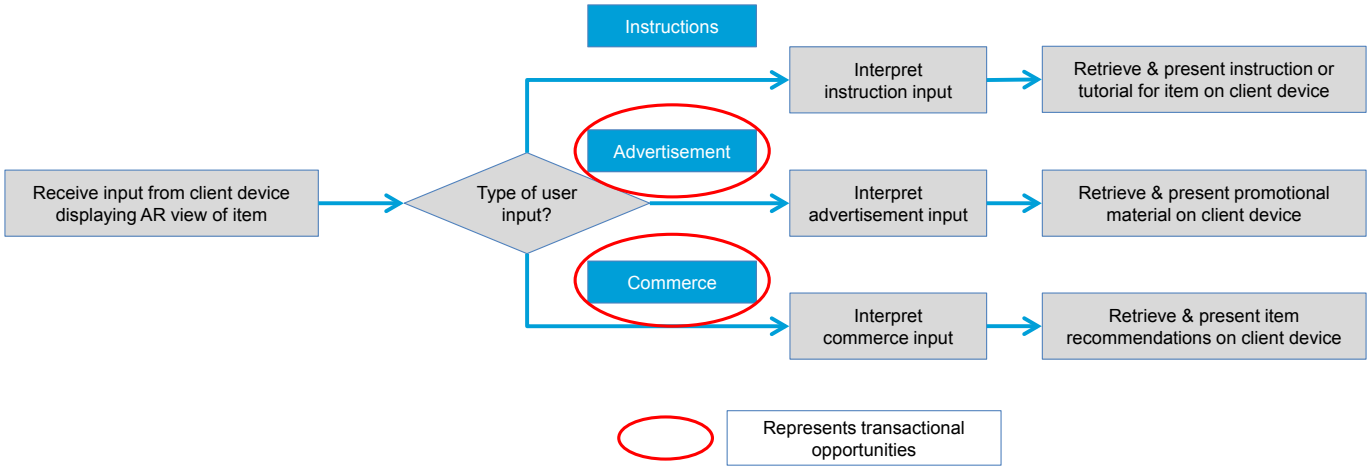
VR/AR has the potential to change how consumers make purchases

In general, VR/AR should help us accelerate the trend towards m-commerce and away from physical commerce, in our view. We note a few developments that support this view.

1. VR commerce has the potential to modify the composition and market size of digital commerce. The ability for digital shoppers to "see items in real size and form" was the top reason for consumer interest in VR, according to an Ericsson Consumer Lab survey of global smartphone users. The VR commerce experience still in its infancy, but is seeing broad-based investment from retailers and digital platforms, including Alibaba, TOMS, Ikea, and Amazon to name a few. Earlier in 2016, Alibaba announced that it had created its own VR research lab to work with its retailers to integrate VR into the shopping experience. Existing use-cases that support this view include Lowe's using the technology to help consumers pick out the right combination of home improvement products and IKEA using it for items like furniture that have historically been purchased in physical locations.

2. In April 2016, PayPal was granted a patent titled "Augmented Reality View of Product Instructions". The patent describes a technology where a consumer can use an AR-enabled device (e.g. smartphone, glasses, or other wearable) to identify real-life, physical products and display instructions and assembly information in the AR environment and identify necessary accessories. Perhaps most importantly, the technology also produces product recommendations, product reviews, and special offers. This creates opportunities for AR commerce that can drive payment volume. The flow process outlined in PayPal's patent is illustrated in the figure below.

**Figure 142. How AR Can Create Commerce/ Transactional Opportunities – Roughly Based on PayPal AR Patent**




Source: Citi Research

The way payments are processed by issuers is likely to remain unchanged

While we are calling for an accelerated shift away from physical commerce due to VR/AR, we note that the heart of the payments process is likely to be unchanged from the current m-commerce approach. Of course, the initial form-factor changes – for example, the wave of a hand or nodding one's head in a particular way may initiate a transaction. But once payment credentials enter the system, the same process should follow. The primary parties– merchant processors, networks, and issuers/financial institutions continue to perform the same underlying functions to process a payment, in our view.

These are still early days within the VR/AR evolution and the underlying business models are also new. However, the building blocks from a payments perspective are likely to be: (1) robust support for VR/AR application developers – this is akin to Braintree's initial support for mobile developers, which was based on the assumption that payments is an inherently complex business and success would belong to those who reduced friction and hid complexity; (2) fast and straightforward payment API integration; (3) a frictionless interface/ payment process (this could be provided by a payment processor or a third party) necessary for seamless, in-context purchases; and (4) omni-channel payments capabilities that support payment processing across channels (e.g. e-commerce / m-commerce / AR-commerce / VR-commerce, in-store commerce, etc.).

## Delving Further Into VR/AR Considerations for Processors

At a certain point in the evolution, it may be worthwhile to separate out AR from VR rather than develop support applications together.

Fundamentally, VR detaches one from reality and provides an immersive experience. Examples include retail (e.g., Lowe's home improvement), sports, education, training, gaming, defense / aerospace, etc. On the other hand, AR provides incremental information while still being rooted in reality – the simplest example of it will be clear to fans of American football…the first down line! It provides incremental information to the viewer that is not a part of the reality of the football field. More meaningful examples are in manufacturing, retail (e.g., IKEA's attempt to superimpose furniture against a rendering of your home), trading, healthcare, product purchases driven by smartphone image recognition (Visa-Blippar collaboration), and so on.

AR is more favorable for commerce use case due to mobility

Mobility is key in differentiating AR from VR. As mobility is linked to the usefulness of AR, most AR-related commerce activity is likely to occur on a mobile device or a type of wearable. However, it is important to note that a mobile transaction is not the only outcome of an AR experience – both informational AR applications (e.g. AR directions or mapping) and retailing AR applications (e.g. apparel retailer) could either drive consumers to the store or provide a purchase occasion within the contextual AR experience.

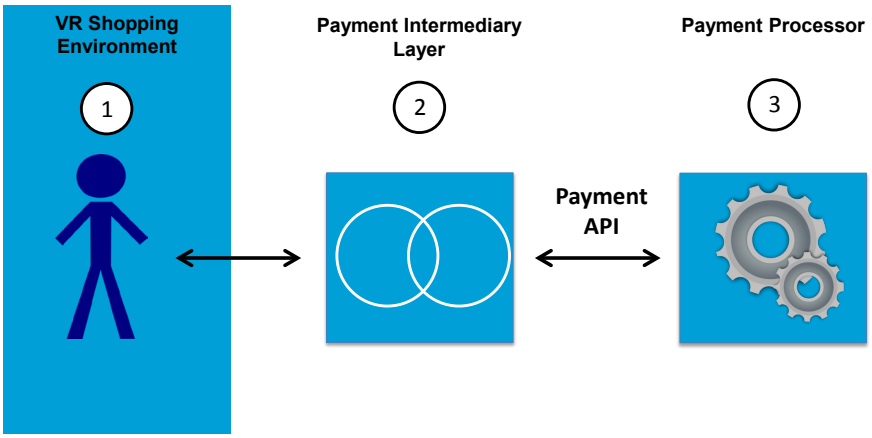
In a VR experience, there is little choice to use a traditional payments experience. Of course, if AR is used primarily from an informational perspective to provide enhanced information (e.g., coupons, special highlighted deals in a grocery aisle, comparison shopping), the AR payment can be a traditional card-based transaction although we admit it seems a bit underwhelming. Generally, the ability for AR application developers to easily integrate with payment processors becomes increasingly important, as does the ability for transactions to be completed with minimal friction without leaving an AR context. The relatively recent proliferation of "one touch" mobile payments from vendors such as Braintree and Stripe make this type of experience possible.

## Some Payments Use Cases

Payment processors have begun work to make VR/AR payments a reality in preparation for future VR- / AR-commerce related applications. We mentioned the PayPal patent in the text above. Some more examples follow that illustrate developments, and potential use cases, for interoperability, and loyalty.

In 2015, Vantiv held a hackathon that focused on the development of technologies that enable immersive (in VR) payments via Vantiv APIs. The winner of the hackathon was PayVR, which developed a technology that allows developers working with Oculus Rift, Sony VR, Google Cardboard, and other VR hardware platforms the ability to accept payments by importing a plugin. An illustrative example of the process is described in the figure below.

Figure 143. Simple Illustrative VR Payments Process




1. Consumer makes physical gesture to confirm a purchase in a VR environment, which activates payment layer plug in.
2. The payment intermediary layer accepts customer & purchase information and accesses the payment processor's API. This step can be outsourced to a third-party with development plug ins.
3. The payment processor accepts the customer & purchase information, which is directed to the proper network for authorization. The returned authorization result is then sent back to the consumer.

Source: Citi Research
Note: There are a number of additional steps and complexities involved in the payment transaction process. We provide a simplified diagram for illustrative purposes.

In March 2016, Mastercard presented the ability to purchase products in VR at the Arnold Palmer Invitational PGA golf tournament. In conjunction with Wearality, a startup that designs VR glasses and wearables, Mastercard provided a VR golf course tour with a professional golfer. Consumers could identify and purchase items, such as a golf shirt or shoes, without leaving the VR experience. More recently, Mastercard announced that AR startup IMG in China had joined its program to support early stage commerce- and financial technology-related companies. IMG provides AR technology services for e-commerce customers in the apparel industry, enabling customers to virtually try on products prior to purchase.

Collaborations that demonstrate AR payments are beginning to hit the market

In June 2016, Visa (Europe) introduced a proof-of-concept AR payment app in collaboration with Blippar, a provider of AR tech/applications, and House of Holland, a designer fashion label. When customers capture an image of an apparel product on their smartphones, the AR application identifies the item. The customer is then able to purchase the item using a pre-registered prepaid, debt, or credit card.

Private label retail card issuers or loyalty solutions providers, such as Alliance Data Systems, could complement retail partner investment in AR store user experience applications. Targeted and dynamic pricing feeds could be provided, based on a consumers' private label card membership, brand loyalty status, and spending behavior. Consumers could visualize discounts or reward options in real-time as they browse in-store, while merchants could dynamically alter their promotions.

Figure 144. Augmented Reality Grocery Shopping Experience

Source: Aisle 411

## IT / BPO Services

As illustrated in Figure 140, IT services companies will inevitably be called in to provide consulting, development and integration services for VR/AR enterprise projects. Companies focused on emerging technology implementation, e.g., Globant and EPAM, are already working on integration projects and pilots in this area.

Employee training, testing, and simulation are areas where VR/AR can be used to help employees get up to speed quickly and in a more immersive way. Whether it is training new employees by using VR to place them in the actual work environment or using a VR simulation to help doctors prep for a surgery, VR/AR has many effective, practical uses here. IT Services companies would also play into the picture by helping to develop the VR/AR software and then integrating it into the companies' existing systems.

IT Services companies will assist in bringing VR/AR projects to reality

Workflow assistance is another area where VR/AR can be utilized that IT Services companies have already done some work in. Examples include VR/AR conference calls that connect employees from different locations and can translate different languages or using AR to place consultants in the operating room to help bring medical expertise cheaply to areas that may not currently have it. A more specific example is Accenture's Augmented Reality Workflow Engine that uses AR glasses to look at QR codes placed in the work environment to overlay images of next steps in the work process (i.e. highlighting a wire that needs to be connected and showing where to connect to) with textual instructions. The solution is customizable to fit client needs, allowing employees to work efficiently without having to constantly look at instructions or seek further help.

Beyond helping companies work through where VR/AR is best used and developing some of the VR/AR content and software, IT Services companies are also helping companies be prepared internally for the rise of VR/AR. VR/AR is likely to create and require a massive amount of data, and companies will need to update and possibly outsource their infrastructure to be prepared for this. With the massive amount of incoming data, security and data privacy along with analytics will also become even more important. For IT Services companies, this figures to benefit some ITO work and also be a boost to the already fast-growing areas of security, analytics, and big data.

# Epilogue

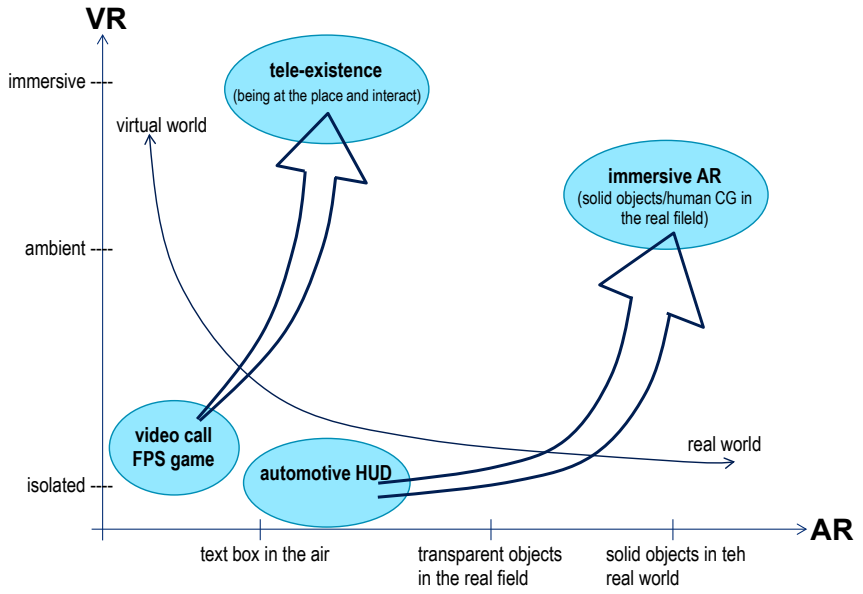
**Kota Ezawa**
Japan Electronics Analyst

Current market forecast models do not necessarily factor in changes to VR/AR device applications and demand for them as their performance improves. This is understandable as there are limits to how far out a meaningful roadmap can be drawn. Over the next 10 years or so, however, we believe both VR and AR devices will steadily evolve.

## VR/AR mapping

VR starts with users viewing a virtual scene in isolation and ultimately evolves into an immersive experience that allows users to feel like part of a virtual world. AR starts by displaying part of a users' actual field of vision in a text box. Semi-transparent landmarks, figures, and other computer graphics are then introduced into the real-world scene in such a way as to appear natural. In the final stage, objects and people that have a convincing life-like quality are introduced and users are able to interact with them (move objects, talk to people, etc.).

**Figure 145. VR and AR are Evolving**




Source: Citi Research

## The three stages of VR

Skype and FaceTime video call services share concepts found in VR. Halo, Metal Gear Solid, and other first-person shooter (FPS) video games are also close to virtual reality. But video calls/FPS video games are a far cry from immersion in a virtual world and are more accurately described as isolated experiences. The next stage is to create a virtual setting, or ambience, around the user. This is achieved by looking at a VR headset display rather than a laptop PC or TV screen. In the case of a roller coaster computer graphic, the user would be engulfed by the screams of other people on the ride.

The final stage of VR evolution is the immersive experience. Users enter a virtual world in which they can roam over hills, hold business discussions with customers, or dance with their grandchildren. This is not just the sensation of watching a virtual world but of actively engaging with it. We expect this will involve users wearing a headset as well as clothing devices (gloves, shoes, pants) that enable the virtual world to respond to their movements.

The three stages of AR

We expect AR to evolve in three stages. The first stage is digital display functionality on vehicle windshields (displaying speed, etc.). This allows drivers to know if they are travelling at a safe speed without having to divert their eyes to the dashboard. However, this type of computer graphic does not follow the driver's line of sight. The next stage is using semi-transparent images to display directions, signals, road signs, and other functions in the driver's field of vision. A feature of the second stage of AR is that the computer graphic works in unison with the movement of vehicle. The final stage is the introduction of life-like computer graphics. In ten years, we think a number of items could be orbiting the kind of globe one buys for children.

**Figure 146. Semi-Transparent Information Overlaid on Actual Scenery**


Source: Pioneer Corporation

**Figure 147. Immersive AR Concept (Augmented Reality Globe)**

Source: Source: By Wilson Teresi (via Wikimedia Commons). (https://commons.wikimedia.org/wiki/File:Augmented_reality_world_globe.png

Potential applications are diverse

We believe VR/AR is likely to have many applications in the leisure and entertainment field, including concerts, sports, horse racing, and amusement parks, as well as commerce and business (conferences, training, exhibitions, travel, and more.). For example, people could watch sporting events in VR. This would not replace the thrill of watching an event live and should thus increase the size of the sports market in net terms. Also, we see potential for pop concerts to be streamed using VR services. We believe the use of VR for sports and arts that are primarily meant to be consumed visually is not far away.

Changing our world

By projecting virtual objects or people in real space through the use of AR, it has become possible to intuitively convey images of objects or people that previously had to be imagined. By superimposing 3D computer-generated imagery over real-time images, AR allows users to view and touch objects from different angles in an almost realistic fashion and to use a gyroscope to adjust views and aspects. This not only offers greater convenience; it may also affect human sensibility. Put another way, humanity's desire to own material things and infrastructure could wane and the importance of objects existing physically before one's eyes could also diminish.

In the world of AR, it is also possible to superimpose text, statistics, or other information forms over real-life images or background scenes. We believe this will bring life changes similar to those triggered by the birth of the Internet. As this technology not only allows explanations of immediate events/phenomena even where there is no prior memory or knowledge, it also makes it possible to obtain information to augment existing knowledge such as up-to-date information and statistics (support ratings, sales, traffic news, etc.). Customizing such information to an individual's needs also appears feasible, especially when linked to profiles, data sets and productivity applications relevant to that user.

The use of VR can simulate environments that give the impression almost of a novel scene. Using a headset or similar device, the VR visitor normally stands in a certain space, or in some cases sits in a chair or lies on a bed. VR not only includes sight and sound, but if sensors corresponding to each of the five senses are applied to the body, the overall virtual experience can deliver a level of awareness that transcends the physical body. For the user, VR heightens the perception of being physically present in a non-physical world, a perception that is created as the user's awareness of physical self is transformed by being immersed in a virtual space. We believe the use of VR in entertainment applications such as games and movies will deliver a relatively more realistic experience. However, we think VR could ultimately result in human consciousness itself being recreated within the virtual environment.

IOT could absorb VR amid advances in networks and computing

We think VR could play a major role in humanity's future. Specifically, we think rapid advances in hyper-capacity networks and ultra-miniature/high-performance computing could see the nascent IoT eventually absorb VR as a key tool for accessing all data on things and events uploaded to and stored on networks. Our near-term roadmap has VR succeeding telephones, TVs, and the Internet as the next major advance in human communications.

As this occurs, we expect VR to be combined with AR to create a virtual space as precise and detailed as a photograph. We expect further technological advances to eventually enable the five human senses to be re-created in the virtual environment as well as—ultimately—human consciousness itself. This outlook for the future is currently transitioning from mere futurist vision to the actual roadmap used by scientists involved in computers, IoT, and VR. We think future technological advances will make VR/AR a platform that transforms human lifestyles.

# Appendix

| Anyways | |
|---|---|
| Samsung Gear VR | http://www.samsung.com/jp/product/gearvr/#experience |
| Google VR smartphone | http://www.nikkei.com/article/DGXLASGN19H11_Z10C16A5000000/ |
| Samsung Gear VR, Oculus | http://www.nikkei.com/article/DGXLASGM25H4W_V20C15A9FF1000/?n_cid=SPTMG002 |
| Main 20 HMD | http://www.dronediy.jp/2016/01/2016-vr-htc-oculus-razer.html |
| Google Hololens | http://mainichi.jp/premier/business/articles/20160308/biz/00m/010/009000c |
| Google Daydream Movie | http://gigazine.net/news/20160519-google-vr-daydream/ |

| AC (Arcade game) | |
|---|---|
| Oculus Arcade | http://juggly.cn/archives/165020.html |
| VR ZONE Project i Can | https://project-ican.com/ |
| Arcade Beta | http://www.moguravr.com/arcade-beta/ |
| Virtuality Club in Russia | https://virtualrealityreporter.com/virtual-reality-club-russia-top-vr-games-vrarcade/ |
| Oculus' VR Arcade | http://arstechnica.com/gaming/2015/11/oculus-VR/ARcade-is-a-lonely-artificial-placebut-it-doesnt-have-to-be/ |

| Amusement park | |
|---|---|
| The Void | http://japanese.engadget.com/2015/05/10/vr-the-void-2016/<br>http://www.roadtovr.com/the-void-latest-impressions-from-a-theme-park-industry-veteran/ |
| Recruit Amusement Park | http://japanese.engadget.com/2016/03/22/vr-vr/ |
| Six Flag | http://app-review.jp/news/293453<br>http://venturebeat.com/2016/03/03/samsung-and-six-flags-partner-to-launch-virtual-reality-roller-coasters-at-9-u-s-amusement-parks/ |
| eMotion | http://www.moguravr.com/gearvr-hospital/ |
| Yahoo trend coaster | http://www.sensors.jp/post/post_12.html |

| Medical, Healthcare | |
|---|---|
| VR training simulator | http://www.gadeliusmedical.com/ja/products/trainingsimulators/virtualreality.html |
| Human Centric Design | http://techon.nikkeibp.co.jp/atcl/feature/15/327441/021000038/?ST=health |
| 7 examples of VR, AR Healthcare | https://japan.techrepublic.com/article/35078964.htm |
| VR in health care | http://www.strategyr.com/pressMCP-7662.asp |
| VR in health care market trends | http://www.strategyr.com/MarketResearch/Virtual_Reality_VR_In_Healthcare_Market_Trends.asp |
| VR in health care where is innovation | http://techcrunch.com/2015/09/16/virtual-reality-in-healthcare-wheres-the-innovation/ |
| 10 ways virtual reality is revolutionizing medicine and healthcare | http://www.techrepublic.com/article/10-ways-virtual-reality-is-revolutionizing-medicine-and-healthcare/ |
| Oculus health care | http://www.forbes.com/sites/quora/2014/06/18/how-can-the-oculus-rift-be-used-for-healthcare/#405273127718 |
| Oculus medical | http://www.reuters.com/article/us-oculus-medicine-idUSKBN0OR02620150611 |

| Real estimate | |
|---|---|
| VR real estimate | http://www.fdj.com/2015/12/1388.html |
| Finding for housing to use VR, summo | http://www.itmedia.co.jp/pcuser/articles/1603/14/news047.html |
| Finding for housing to use VR, team lab | http://www.moguravr.com/hacoscoapartmentvr/ |
| making plan for city | http://www.aoi-kokusaiblog.com/festivals/26199 |
| 3D city data, Panasonic | http://nge.jp/2015/01/12/post-92130 |
| Now you can shop for luxury homes in virtual reality | http://fortune.com/2015/09/09/virtual-reality-real-estate/ |
| WSJ Virtual-Reality Tours Come to Commercial Real Estate | http://www.wsj.com/articles/the-office-space-in-your-head-1435541344 |

| Travel, Hotel | |
|---|---|
| Marriot hotel, VR | http://social-design-net.com/archives/24733 |
| Example, cloud finding " traveling in the world for seniors " | https://readyfor.jp/projects/2643 |
| HIS to use oculus, can be experiencing in Hawaii | http://panora.tokyo/1773/ |
| World travel in Hacosco | https://utage.headwaters.co.jp/blog/?p=5330 |
| Recommended 10 sites | http://www.digitaltrends.com/virtual-reality/best-vr-apps-for-travel/ |
| How Oculus and Cardboard Are Going to Rock the Travel Industry | http://www.bloomberg.com/news/articles/2015-06-19/how-oculus-and-cardboard-are-going-to-rock-the-travel-industry |
| Article from TRAVEL WEEKLY | http://www.travelweekly.com/Travel-News/Travel-Technology/Virtual-reality-check |
| VR: Changing The Way We Travel | http://media.bemyapp.com/vr-change-way-travel/ |

| Media (TV, Movie, News) | |
|---|---|
| Europe's first VR cinema in Amsterdam | http://thebridge.jp/2016/03/virtual-reality-movie-theaters-are-now-a-thing |
| VR Theater in Japan | http://interpia.ne.jp/vr/theater/ |
| talking about VR movie from Steven Spielberg | http://japanese.engadget.com/2016/05/21/vr/ |
| Nokia, for Disney movie | http://www.moguravr.com/ozo-disney/ |
| How Virtual Reality Might Change TV Shows | https://www.pastemagazine.com/articles/2015/10/how-virtual-reality-might-change-tv-shows.html |
| IMAX VR theater in the states | http://www.moguravr.com/imax-vrtheater/ |
| NHK VR News ( can connect information to NY times, ABC news) | http://www.gizmodo.jp/2016/02/20160219nvr_nhk360.html |
| Nomads application of VR | http://www.moguravr.com/nomads-gearvr/ |

| E Commerce | |
|---|---|
| Retail sector | http://forbesjapan.com/articles/detail/11945 |
| VR shopping mall | http://www.gizmodo.jp/2015/09/vrgo.html |
| Kabuki | http://news.livedoor.com/article/detail/11504889/ |
| Alibaba | http://techcrunch.com/2016/03/17/alibaba-is-working-to-bring-virtual-reality-into-its-e-commerce-services/ |
| Sixense | http://sixense.com/vretail |

| Factory Operation | |
|---|---|
| Industrial VR | |
| Komatsu: Five-screen VR system for construction equipment design | http://kenplatz.nikkeibp.co.jp/atcl/knpcolumn/14/546679/011800015/?P=3 |

| For Business | |
|---|---|
| 6 amazing uses for virtual reality in business | http://www.computerworld.com/article/2931551/emerging-technology/6-amazing-uses-for-virtual-reality-in-business.html |

| Others | |
|---|---|
| Five markets leveraging VR: retail, travel, real estate, autos, photography | http://readwrite.jp/trend/25109/ |
| 360 Video at YouTube supported by Facebook | https://www.youtube.com/channel/UCzuqhhs6NWbgTzMuM09WKDQ |
| Colums | http://curazy.com/archives/135181 |
| Gree and Fuji Television "F&G VR WORKS" | http://www.gizmodo.jp/2016/05/gree-fujitv-vr.html |
| Facebook considering e-commerce using VR goggles | http://iikurakoichi.cocolog-nifty.com/blog/2015/04/facebooke--1504.html |
| Let's experience VR! Nine popular VR software products and gadgets | http://liginc.co.jp/199377 |
| NASA training | https://www.bloomberg.co.jp/news/articles/2016-01-04/NZUUGK6K50XS01 |
| What Americans Really Think About Virtual Reality | http://www.fastcompany.com/3053235/tech-forecast/what-americans-really-think-about-virtual-reality |
| Facebook Oculus | |
| Google Magic Leap | http://www.newsweekjapan.jp/yukawa/2016/04/45magic-leap.php<br>http://japanese.engadget.com/2016/04/29/hololens-jal/ |

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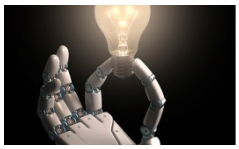

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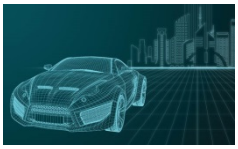

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## Notes

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## Key Insights regarding the future of Virtual and Augmented Reality

### TECHNOLOGY

Technological advances over the past thirty-plus years have moved from PCs to the Internet to mobile phones and eventually to VR/AR. / Our near-term roadmap has VR succeeding telephones, TVs and the Internet as the next major advance in human communications. We expect VR to be combined with AR to create a virtual space as precise and detailed as a photograph.

### SHIFTING WEALTH

Traditional retailers were disrupted by the rise of e-commerce, as customers switched from shopping in-store to shopping on their PCs and eventually on their smartphones. / AR commerce consumer behavior is likely to be similar to current mobile commerce. We expect users to use AR headsets in the same way that they currently use smartphones to make purchases, enjoy content, and make bookings for a variety of services.

### INNOVATION

VR/AR has been considered a "technology of the future" for many years but 2016 will see the actual launch of different VR systems into the marketplace. / Over the next 5-10 years we believe VR/AR will become part of daily life in areas like shopping, travel, and leisure & entertainment, driven first by hardware growth and then by commercial & consumer applications.